U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-294 791

User's Guide for RAM Volume I. Algorithm Description and Use

(U.S.) Environmental Sciences Research Lab,
Research Triangle Park, NC

Nov 78

United States
Environmental Protection
Agency

Environmental Sciences Research
Laboratory
Research Triangle Park NC 27711

EPA-600/8-78-016a
November 1978

Research and Development

PB 294791

EPA

User's Guide For RAM

Volume I. Algorithm Description and Use

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the SPECIAL REPORTS series. This series is reserved for reports which are intended to meet the technical information needs of specifically targeted user groups. Reports in this series include Problem Oriented Reports, Research Application Reports, and Executive Summary Documents. Typical of these reports include state-of-the-art analyses, technology assessments, reports on the results of major research and development efforts, design manuals, and user manuals.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-78-016a	2.
3. RECIPIENT'S ACCESSION NO. PB294791	
4. TITLE AND SUBTITLE USER'S GUIDE FOR RAM Vol. I. Algorithm Description and Use	5. REPORT DATE November 1978
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. Bruce Turner and Joan Hrenko Novak	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Sciences Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	10. PROGRAM ELEMENT NO. 1AA603 AB-25 (FY-78) 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED In-house 14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES	

16. ABSTRACT The information presented in this user' guide is directed to air pollution scientists having an interest in applying air quality simulation models. RAM is the three letter designation for this system of efficient Gaussian-plume multiple-source air quality algorithms and also the primary algorithm for urban areas. These algorithms can be used for estimating air quality concentrations of relatively nonreactive pollutants for averaging times from an hour to a day from point and area sources. The algorithms are applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a good approximation to the flow over the source area considered. Calculations are performed for each hour. Computation time is kept to a minimum by the manner in which concentrations from area sources are estimated using a narrow plume hypothesis and using the area source squares as given rather than breaking down all sources into an area of uniform elements. Options are available to the user to allow use of three different types of receptor locations: (1) those whose coordinates are input by the user, (2) those whose coordinates are determined by the model and are downwind of significant point and area sources where maxima are likely to occur, and (3) those whose coordinates are determined by the model to give good area coverage of a specific portion of the region. Computation time is also decreased by keeping the number of receptors to a minimum. Volume I considers the use and capabilities of RAM, its basis, the organization of the computer program and data requirements.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air pollution *Atmospheric models Algorithms *Dispersion		13 B 14 A 12 A

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 70
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE AC4-A01

EPA Form 2220-1 (9-73)

EPA-600/8-78-016a

November 1978

User's Guide For RAM

Volume I.

Algorithm Description and Use

by

D. Bruce Turner and Joan Hrenko Novak

Meteorology and Assessment Division
Environmental Sciences Research Laboratory

Environmental Sciences Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

A-1

DISCLAIMER

This report has been reviewed by the Environmental Sciences Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

AUTHORS' AFFILIATION

The authors are on assignment with the U. S. Environmental Protection Agency from the National Oceanic and Atmospheric Administration, U. S. Department of Commerce.

FOREWORD

Within the Office of Air, Land, and Water Use, the Environmental Sciences Research Laboratory conducts a research program in the physical sciences to detect, define, and quantify the effects of air pollution on urban, regional, and global atmospheres and the subsequent impact on water quality and land use. This includes research and development programs designed to quantitate the relationships between emissions of pollutants from all types of sources and air quality and atmospheric effects.

The Meteorology and Assessment Division conducts research programs in environmental meteorology to describe the roles and interrelationships of atmospheric processes and airborne pollutants in effective air, water, and land resource management. Developed air quality simulation models (in Fortran computer code) are made available to dispersion model users in computer compatible form by availabliity of a magnetic tape from NTIS (See Preface).

RAM is one of the five dispersion algorithms added to UNAMAP in March 1978. RAM is based upon Gaussian dispersion concepts of steady-state modeling. Limitations are imposed on use of the algorithm by the assumptions of non-reactive pollutants and one wind vector and one stability class as representative of the area being modeled. Also computations made under light wind conditions should be interpreted skeptically. In spite of these limitations RAM provides a useful short-term (hours to a day) algorithm for point and area sources for air pollution impact assessment.

L. E. Niemeyer, NOAA
Director, Meteorology and Assessment Division

PREFACE

One of the research activities of the Meteorology and Assessment Division focuses on the development, evaluation, validation, and application of air quality simulation, photochemical, and meteorological models capable of describing air quality and atmospheric processes affecting the disposition of airborne pollutants, on scales ranging from local to global. Within the Division, the Environmental Applications Branch adapts and evaluates new and existing meteorological dispersion models and statistical technique models, tailors effective models for recurring user application, and makes these models available through EPA's computer network system.

RAM, an adaptation of Gaussian techniques previously used in point source modeling, uses a rapid executing algorithm for area sources based on the narrow plume hypothesis and has numerous options available to increase user utility. RAM is one of the atmospheric dispersion models on the User's Network for Applied Modeling of Air Pollution (UNAMAP) system. The UNAMAP system may be purchased on magnetic tape from the National Technical Information Service (NTIS) for use on the user's computer system.

Although attempts are made to thoroughly check out computer programs with a wide variety of input data, errors are occasionally found. In case there is a need to correct, revise, or update this model, revisions may be obtained as they are issued by completing and sending the form on the last page of this guide.

Comments and suggestions regarding this publication should be directed to:

Chief, Environmental Applications Branch
Meteorology and Assessment Division (MD-80)
Environmental Protection Agency
RESRCH TRI PK, NC 27711

Technical questions regarding use of the model may be asked by calling (919) 541-4564. Users within the Federal Government may call FTS: 629-4564. Both volumes of the User's Guide are available from NTIS, Springfield, Va. 22161.

The magnetic tape containing all Fortran source codes for RAM, as well as for ten other dispersion models, may be ordered from Computer Products, NTIS. Ask for UNAMAP (Version 3), PB 277 193.

ABSTRACT

The information presented in this user's guide is directed to air pollution scientists having an interest in applying air quality simulation models. RAM is the three letter designation for this system of efficient Gaussian-plume multiple-source air quality algorithms and also the primary algorithm for urban areas. RAM is a method of estimating short-term dispersion using the Gaussian steady-state model. These algorithms can be used for estimating air quality concentrations of relatively non-reactive pollutants for averaging times from an hour to a day from point and area sources. The algorithms are applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a good approximation to the flow over the source area considered. Calculations are performed for each hour. Hourly meteorological data required are wind direction, wind speed, temperature, stability class, and mixing height. Emission information required of point sources consists of source coordinates, emission rate, physical height, stack diameter, stack gas exit velocity, and stack gas temperature. Emission information required of area sources consists of south-west corner coordinates, source side length, total area emission rate and effective area source-height. Computation time is kept to a minimum by the manner in which concentrations from area sources are estimated using a narrow plume hypothesis and using the area source squares as given rather than breaking down all sources into an area of uniform elements. Options are available to the user to allow use of three different types of receptor locations: 1) those whose coordinates are input by the user, 2) those whose coordinates are determined by the model and are downwind of significant point and area sources where maxima are likely to occur, and 3) those whose coordinates are determined by the model to give good area coverage of a specific portion of the region. Computation time is also decreased by keeping the number of receptors to a minimum. Volume I considers the use and capabilities of RAM, its basis, the organization of the computer program, and data requirements. Volume II presents RAM example outputs, typical run streams, variable glossaries, and Fortran source codes.

CONTENTS VOLUME I

Foreward iii
Preface. iv
Abstract v
Figures. ix
Acknowledgements x
1. Introduction 1
2. Recommendations. 3
Uses. 3
Algorithm Assumptions 3
Proper use of RAM 8
Special problems that may be encountered using the frequency distribution version (RAMF) of RAM. 9
3. Theoretical Basis for RAM. 11
Dilution by the wind. 11
Dispersion results in Gaussian distributed cross sections 11
Steady-state conditions 11
Concentration - sum of individual contributions . 11
Plume rise for point sources. 12
Effluent rise for area sources. 17
Concentrations from point sources 17
Concentrations from area sources. 18
4. Organization of Computer Programs. 19
Interrelationship of eight main programs. 19
Brief descriptions of programs 22
Brief descriptions of subroutines 28
5. Data Requirements. 32
RAMBLK. 32
RAMQ. 32
Meteorological data and RAMMET. 35
RAM and RAMR. 37
RAMF and RAMFR. 42
CUMF. 43
6. Algorithm Capabilities 44
Typical use of RAM. 44
Discussion of RAM example 46
Typical RAMR use. 50
Typical RAMF use. 50
References 52
Appendix 54

Preceding page blank

CONTENTS VOLUME II

Foreward. iii
Preface iv
Abstract v
Figures ix
Acknowledgements. x
1. Introduction 1
2. System overview and glossary 2
3. RAMQ 20
Input data formats (RAMQDOC). 20
Run-stream example. 21
Output example. 22
Fortran source program listings 26
4. RAMMET 36
Input data formats (RAMMETDOC). 36
Run-stream example. 38
Output example. 40
Fortran source program listings 41
5. RAM. 47
Input data formats (RAMDOC) 47
Run-stream example. 52
Output examples 53
Fortran source program listings 72
Program to read the partial concentration output file (PARTC) 111
Format of punch card output (PUNCHCARD) 113
6. RAMF 115
Input data formats. 115
Run-stream examples 120
Output example. 126
Fortran source program listings 132
Program to read the hourly output file (RAMFHOUR) . 146
Program to read the daily output file (RAMFDAY) . . 148
7. RAMR 150
Fortran source program listings 150
8. RAMFR. 176
Fortran source program listings 176
9. CUMF 188
Input data formats. 188
Run-stream example. 188
Output example. 189
Fortran source program listings 201
10. RAMBLK 207
Input data formats. 207
Run-stream example. 207
Output example. 208
Fortran source program listings 212

FIGURES

Number		Page
1	Interrelationships of RAM system main programs	20
2	Subroutine structure of RAM and RAMR	25
3	Subroutine structure of RAMF and RAMFR	27

TABLE

Number		Page
1	Exponents for Wind Profile	13

ACKNOWLEDGMENTS

The authors appreciate the assitance of Adrian D. Busse for placing RAM into the UNAMAP system, and the helpful discussions with John S. Irwin and K. L. Calder.

We appreciate the suggestions for changes received from the Regional Meteorologists and other contributors in EPA regions. These suggested changes arose from their experience in running provisional versions of RAM.

RAM bears the initials of Robert A. McCormick who directed the meteorology program of the Federal air pollution control effort from June 1958 until the time of his retirement in January 1973. His dedicated leadership, encouragement, advice, and counsel throughout this peirod are greatly appreciated.

The assistance of Theresa Burton, Caryl Whaley, Lea Prince, Nancy Beasley, Bonnie Kirtz, Carolyn Johnston, Sandy Bryant, Tom Pierce, and especially that of Pamela Hinton and Joan Emory is gratefully acknowledged. We thank Ralph Soller for the use of his slide showing point and area sources for the cover.

1. INTRODUCTION

The RAM system includes four dispersion algorithms. The purpose of formulating RAM is to provide a readily available computer program based on the assumptions of steady-state Gaussian dispersion. The principal algorithm, RAM, can be used for short-term (one-hour to one-day) determination of urban air quality resulting from pollutants released from point and/or area sources.

The algorithms are applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a reasonable approximation of the flow over the source area considered. A single mixing height and a single stability class for each hour are assumed representative of the area. The use of the RAM is restricted to relatively nonreactive pollutants.

Emission information required of point sources consists of source coordinates, emission rate, physical height, stack diameter, stack gas exit velocity, and stack gas temperature. Emission information required of area sources consists of south-west corner coordinates, source side length, total area emission rate, and effective area source height. Output consists of calculated air pollutant concentrations at each receptor for hourly averaging times and a longer averaging time as specified by the user. Contributions to the concentration in the two categories -- 1) from point sources, and 2) from area sources -- are also given on output. The contributions to the concentration from specific point and area sources can be obtained at the option of the user.

Computations are performed hour by hour as if the atmosphere had achieved a steady-state condition. Therefore, errors will occur where there is a gradual buildup (or decrease) in concentrations from hour to hour, such as with light wind conditions. Also under light wind conditions the definition of wind direction is likely to be inaccurate, and variations in the wind flow from location to location in the area are quite probable.

Briggs' plume rise equations are used to estimate effective height of point sources. Concentrations from the point sources are determined using distance crosswind and distance upwind from the receptor to each source.

Considerable time is saved in calculating concentrations from area sources by using a narrow plume simplification which considers sources at various distances on a line directly upwind from the receptor to be representative in the crosswind direction of the sources at those distances affecting the receptor. Area source sizes are used as given in the emission inventory in lieu of creating an internal inventory of uniform elements.

Options are available to allow the use of three different types of receptor locations: 1) those whose coordinates are input by the user, 2) those whose coordinates are determined by RAM and are downwind of significant point and area sources where maxima are likely to occur, and 3) those whose coordinates are determined by RAM to give good area coverage of a specific portion of the region. Options are also available concerning the detail of output produced.

Urban planners may use RAM to determine the effects of new source locations and of control strategies upon short-term air quality. If the input meteorological parameter values can be forecast with sufficient accuracy, control agency officials may use RAM to predict ambient air quality levels, primarily over the 24-hour averaging time, to 1) locate mobile air sampling units, and 2) assist with emission reduction tactics. Especially for control tactics, diurnal and day-to-day emission variations must be considered in the source inventory input to the model. For most of these uses, the optional feature to assist in locating maximum points should be used. Computations are organized so that execution of the program is rapid, thus real-time computations are feasible.

2. RECOMMENDATIONS

USES

The principal algorithm in the system, RAM, is a short-term (one-hour to one-day) urban algorithm for estimating air quality from point and area sources.

Effects of either control strategies or tactics for specific short-term periods may be examined by users. The expected effect of a proposed source or sources can also be determined.

The spatial variation in air quality throughout the urban area or in a portion of the area for specific periods can be estimated.

In a forecast or predictive mode such as over a 24-hour period, the algorithm can assist in locating mobile or portable air samplers and to assist with emission reduction tactics. Successful use of RAM in the forecast mode is contingent on the validity of the algorithm assumptions and certainly on the ability to forecast both the input meteorological parameter values and the input emission parameter values.

ALGORITHM ASSUMPTIONS

Gaussian Plumes

Calculations of concentrations from point sources may be made by diluting the emissions with the mean wind speed and considering the time-averaged plumes over 1-hour periods to have Gaussian (normal) distributions perpendicular to the plume centerline in the horizontal and vertical.

Narrow Plume Simplification

Calculations of concentrations from area sources are made by considering area sources at various distances on a line directly upwind from the receptor to be representative of the sources at those distances that affect the receptor. This assumption is best fulfilled by gradual rather than abrupt

changes in area emission rates from adjacent area sources. The narrow plume simplification is considered in more detail in the next chapter.

Meteorological Conditions Representative of Region

The meteorological input for each hour consists of a value for each of the four parameters: wind direction, wind speed, temperature, stability class, and mixing height, all of which should be representative of the entire region containing the sources and receptors. Mixing height is required only if the stability is neutral or unstable.

Steady-state

Calculations are made as if the atmosphere had reached a steady state. Concentrations for a given hour are calculated independently of conditions for the previous hour or preceding hours.

Concentration, Sum of Contributions

The total concentration for a given hour for a particular receptor is the sum of the estimated contributions from each source.

Vertical Stability

Except for stable layers aloft, which inhibit vertical dispersion, the atmosphere is treated as a single layer in the vertical with the same rate of vertical dispersion throughout the layer. Complete eddy reflection is assumed both from the ground and from the stable layer aloft given by the mixing height.

Mixing Height

If vertical temperature soundings are available from a representative location, they should be used with hourly surface temperatures to estimate hourly mixing heights for periods with neutral or unstable stability. If a series of National Weather Service hourly data are being processed by the program RAMMET, two values of mixing height per day are required. These are the maximum and minimum mixing heights as defined by Holzworth (1972). RAMMET provides a crude interpolation to obtain hourly mixing heights. This interpolation does not consider hourly surface temperatures. Substitution of an improved method for mixing height will be made in a later version of RAM.

Wind Speeds and Directions

Wind speeds and directions should be hourly averages (National Weather Service hourly observations are really not hourly averages but are averages of a few minutes at the time of the observation, usually 5 to 10 minutes prior to the hour). Input winds should be representative of the entire region being modeled and for a height 10 meters above the ground surface.

The increase of wind speed with height is included based upon a power law profile. The exponent is dependent upon the stability classification and surface roughness effects. For any given hour, winds at various altitudes above ground are likely to deviate considerably from this climatological mean profile. The exponents are given in Section 3.

There is no inclusion of directional shear with height. This means that the direction of flow is assumed to be the same at all heights over the region. The taller the effective height of a source, the larger the expected error in direction of plume transport. Although the effects of surface friction are such that wind direction usually veers (turns clockwise) with height, the thermal effects (in response to the horizontal temperature gradient in the region) can overcome the effect of friction and cause backing (turning counterclockwise with height) instead of veering.

In the program RAMMET, which processes National Weather Service hourly observations, the wind directions, which are reported to the nearest 10°, are altered by use of a random generated number from 0 to 9 which is used to add -4° to +5° to the wind vector. The purpose of this is to prevent an extreme overestimate of concentration at a point downwind of a source during a period of steady wind when sequential observations are from the same direction. Rather than allow the plume centerline to remain in exactly the same position for several hours, the alteration allows for some variation of the plume centerline within the 10° sector. Although this can in no way simulate the actual sequence of hourly events (wind direction to 1° accuracy cannot be obtained from wind direction reported to the nearest 10°), such alterations can be expected to result in concentrations over a period of record to be more representative than those obtained using winds to only the 10° increments reported. (Sensitivity tests of this alteration for single

sources have indicated that, where a few hours of unstable conditions are critical to producing high concentrations, the resulting concentrations are extremely sensitive to the exact sequence of random numbers used, such as two wind directions 1° apart versus two wind directions 9° apart. Differences of 24-hour concentrations from a single source by 40 to 50 per cent have appeared in the sensitivity tests due just to the alteration.) It is therefore desirable to use wind information as accurate as possible as input into RAM.

Dispersion Parameter Values

The dispersion parameter values representative for urban areas are those recommended by Briggs and included in Figure 7 and Table 8 of Gifford (1976). These are used in the two urban algorithms in the RAM system, RAM and RAMF, which are discussed in Section 4.

The dispersion parameter values representative for open countryside are the Pasquill-Gifford curves (Pasquill, 1961; Gifford, 1960) which appear in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970) and also appear as Figure 2 in Gifford (1976). These are used in the two rural algorithms in the RAM System, RAMR and RAMFR, which are discussed in Section 4. The subroutines used to determine the open-countryside parameter values are the same as in the UNAMAP programs PTDIS and PTMTP (U.S. Environmental Protection Agency, 1974).

Plume Rise

Plume rise from point sources is calculated using the methods of Briggs (1969, 1971, 1972, 1973, 1975). Although the plume rise from point sources is usually dominated by buoyancy, plume rise due to momentum is also considered. Merging of nearby buoyant plumes is not considered. Stack downwash is considered, but building downwash is not.

The variation of effective height of emission from area sources as a function of wind speed is thought to be an important factor in properly simulating dispersion in urban areas. Since this effect is seldom considered in the compilation of urban area emission inventories, it is difficult to have the appropriate parameters to estimate this effect. This effect can be accounted for in RAM. The methodology used is explained in Section 3.

Emission Inventories

Since for similar meteorological conditions the contribution to the concentration at a receptor from a source is directly proportional to emission rate from that source, it is imperative to have emissions expressed accurately. Since many air pollutant sources vary emissions with time, such as by hour of the day or weekdays vs. weekends, attempts should be made to include such variations. For cases that have complete emissions information, it is usually necessary to devise a system that will calculate and store hourly emissions for the period of record to be simulated. This can be accomplished independently of RAM. RAM is designed to accept hourly emissions in addition to annual emission rates that establish a correspondence between emissions and exit velocity.

Removal or Chemical Reactions

Transformations of a pollutant resulting in loss of that pollutant throughout the entire depth of each plume can be approximated by RAM. This is accomplished by an exponential decrease with travel time from the source. The input parameter is the time expected to lose 50% (half-life) of the emitted pollutant. RAM does not have the capability to change this parameter value during a given run. If the loss to be simulated takes place through the whole plume without dependence upon concentration, then the exponential loss may provide a reasonable simulation if the loss rate is realistic. However, if the loss mechanism is selective, such as impaction with features on the ground surface, reactions with materials on the ground, or dependence on the concentration in a given small parcel of air (requiring consideration of contributions from all sources to this parcel), the loss mechanism built into RAM will not be very adequate.

Topographic Influences

RAM is designed for application over level or gently-rolling terrain where the assumption of a flat plane used in the algorithm is reasonable. Dispersion parameters for the urban algorithms, RAM and RAMF, in the RAM systems are representative of surface roughness over urban areas ($z_o \simeq 1$ m). Dispersion parameters for the rural algorithms, RAMR and RAMFR, are representative of surface roughness over rural areas ($z_o \simeq 0.03$ m). Heights of re-

ceptors (a single height for all receptors is used for a given run) are heights above ground level, not the height of the local ground level with respect to ground level at some other point. The algorithms in the RAM system have no influences of topography incorporated, and some difficulties might be expected in attempting to do so. Under unstable conditions plumes may tend to rise over terrain obstructions. Under stable conditions leveled-off plumes may remain at nearly the same mean-sea-level height but may be expected to alter the plume path in response to the terrain features, thus having a different wind direction locally than that specified for the region.

Fumigation

The transitional phenomenon of fumigation, the elimination of an inversion layer containing a stabilized plume from below causing mixing of pollutants downward which results in uniform concentrations with height beneath the original plume centerline, is not included in calculations made by RAM. Conditions specified for each hour are calculated as if a steady-state had been achieved for those specified conditions.

PROPER USE OF RAM

The closer the situation to be simulated agrees with the assumptions stated above, the greater the expectation of reasonable results. The narrow plume simplification is most reasonable for situations where there are no great variations in area emission rates for adjacent area sources.

The higher the physical and resulting effective heights of point sources, the greater the chance for poorer results since actual directional shear in the atmosphere, not included in the algorithm, will cause plumes to move in directions different from the direction input to the model. Also, the higher the source height, the greater the potential for encountering layers in the atmosphere having dispersion characteristics different from those being used.

As pointed out above, it is necessary to properly consider variations in emissions.

Reliable meteorological inputs are also necessary. The light wind situation is most likely to violate assumptions, since variations in the flow over the region are likely to occur, and the slower transport may cause

buildup of pollutants from hour to hour. Unfortunately, these are the kinds of conditions that are likely to be associated with maximum 3-hour and 24-hour concentrations in urban areas. These light wind situations do not conform to the assumptions of Gaussian steady-state models. Research is underway on models more appropriate for these situations.

RAM is not appropriate for making concentration estimates for topographic complications. The greater the departure from relatively flat terrain conditions, the greater the departure from the assumptions of the algorithm.

RAM is most applicable for pollutants that are quite stable chemically and physically. A general loss of pollutant with time can be accounted for by the algorithm. Selective removal or reaction at the plume-ground interface or dependence upon concentration levels is not capable of being well handled by RAM.

SPECIAL PROBLEMS THAT MAY BE ENCOUNTERED USING THE FREQUENCY DISTRIBUTION VERSION(RAMF) OF RAM

RAMF, a version of RAM that has been changed so that many of the options of RAM cannot be used, calculates 24-hour concentrations (by hour-by-hour simulation) over a relatively long period of record, such as a year. A principal purpose of utilizing this version of RAM would be to identify 24-hour periods that produce high concentrations so that these periods can be further examined to compare concentrations with air quality standards. Current air quality standards are written so that the extremes are very important. The concentrations for the day out of the year with the highest concentrations and the day with the second highest concentrations are required for comparisons with Federal ambient air quality standards. Because of the difficulties with light winds discussed above, daily concentrations for such periods may be underestimated.

In order to make computations as economical as possible, it is desirable to keep the number of receptor locations to a reasonably small number. Computer costs of running RAM are approximately directly proportional to the number of receptor points. Also in order to have the same receptor numbers refer to the same locations (coordinates) throughout a run of RAMF, the

option to locate receptors downwind of significant sources cannot be used. Therefore, with a limited number of receptors and difficulty with the light wind days, it is difficult to determine both the days with the highest and second highest concentrations and the location of the maximum concentration on those days. It appears that several runs with careful examination of output may be required for optimum analysis.

3. THEORETICAL BASIS FOR RAM

The basis for RAM is also discussed in Novak and Turner (1976) which is included in this users guide as the Appendix.

DILUTION BY THE WIND

Emissions from continuous sources are assumed to be stretched along the direction of the wind by the speed of the wind. Thus the stronger the wind, the greater the dilution of the emitted plume. To account for an increase in wind speeds with height from point of measurement to stack top, a power law increase with height is used. The exponent used is a function of stability.

DISPERSION RESULTS IN GAUSSIAN-DISTRIBUTED CROSS SECTIONS

The time-averaged concentration distributions through a dispersed plume resulting from a continuous emission from a point source or an area element are considered to be Gaussian in both the horizontal and vertical directions. Modification of the vertical distribution by eddy reflection at the ground or at a stable layer aloft is allowed. This eddy reflection is accomplished by a "folding back" of the portion of the distribution that would extend beyond the barrier if it were absent. This is equivalent to a virtual image source beneath the ground (or above the stable layer).

STEADY-STATE CONDITIONS

Concentration estimates are made for each simulated hourly period using the mean meteorological conditions for that hour as if a steady-state condition had been achieved. Steady-state Gaussian plume equations are used for point sources, and the integrations of these equations are used for area sources.

CONCENTRATION—— SUM OF INDIVIDUAL CONTRIBUTIONS

The total concentration of a pollutant at a receptor is taken as the sum of the individual concentration estimates from each point and area source

affecting that receptor, that is, concentrations are additive. Concentration estimates for averaging times longer than one hour are determined by arithmetic averaging the hourly concentrations during the period.

PLUME RISE FOR POINT SOURCES

The methods of Briggs have been used to include effects of downwash in the lee of the stack, plume rise due to momentum, and plume rise due to buoyancy.

In the preprocessing of the emission data which ranks the point sources in order of the significance of their expected impact, only the rise due to buoyancy is considered since this is expected to be the dominant effect in plume rise. Also, in determining the distance to maximum concentration that will allow the algorithm to place receptors downwind of point sources, only the rise due to buoyancy is considered.

However, in the computation of the effect of each point source upon receptors for each simulated hour, all three of the above mentioned effects--stack downwash, momentum plume rise, and buoyant plume rise-- are considered. These computations will now be discussed in some detail.

Wind Speed

In RAM the input wind speed data are assumed representative for a height of 10 m above ground. The wind speed at the physical stack height h is calculated from:

$$u(h) = u\ (h/10)^{p}$$

where u is the input wind speed for this hour, and the exponent p is a function of stability. If u(h) is determined to be less than 1 m s^{-1}, it is set equal to 1 m s^{-1}.

TABLE 1. EXPONENTS FOR WIND PROFILE

Stability class	URBAN (RAM) exponent	RURAL (RAMR) exponent
A	0.15	0.07
B	0.15	0.07
C	0.20	0.10
D	0.25	0.15
E	0.40	0.35
F	0.60	0.55

Stack Downwash

Modification of the physical stack height to allow for stack downwash is done following the suggestion on page 4 of Briggs (1973). The h' is found from:

$$h' = h + 2 \left[(v_s/u(h)) - 1.5 \right] d \quad \text{for } v_s < 1.5\ u(h)$$

$$h' = h \text{ for } v_s \geq 1.5\ u(h) \quad ,$$

where v_s is stack gas velocity, m s^{-1}, and d is inside stack-top diameter, m. This h' is used throughout the remainder of the plume height computation.

Unstable or Neutral —— Crossover between Momentum and Buoyancy

For most plume rise situations the value of the Briggs buoyancy flux parameter, F, in m^4 s^{-3} is needed. The following equation is equivalent to equation (12), page 63 of Briggs (1975):

$$F = \frac{g\ v_s\ d^2\ \Delta T}{4\ T_s}$$

where $\Delta T = T_s - T$, T_s is stack gas temperature, K, and T is ambient air temperature, K.

For cases with stack gas temperature greater than ambient air temperature, it is necessary to determine whether the plume rise is dominated by momentum or buoyancy. The cross-over temperature difference $(\Delta T)_c$ is determined for F less than 55, and for F greater than or equal to 55. If the difference between stack gas temperature and ambient air temperature, ΔT, exceeds the

$(\Delta T)_c$, the plume rise is assumed to be buoyancy dominated; if less than this amount, the plume rise is assumed to be momentum dominated (see below): 1) For F less than 55, the crossover temperature difference is found by setting Equation (5.2), page 59 of Briggs (1969) equal to the combination of Equations (6) and (7), page 1031 of Briggs (1971) and solving for ΔT. The result is:

$$(\Delta T)_c = 0.0297\ T_s\ v_s^{1/3} / d^{2/3}$$

2) For F equal to or greater than 55, the crossover temperature difference is found by setting Equation (5.2), page 59 of Briggs (1969) equal to the combination of Equations (6) and (7), page 1031 of Briggs (1971) and solving for ΔT. The result is:

$$(\Delta T)_c = 0.00575\ T_s\ v_s^{2/3} / d^{1/3}$$

Unstable or Neutral —— Buoyancy Rise

For situations where ΔT exceeds $(\Delta T)_c$ as determined above, buoyancy is assumed to dominate. The distance to final rise x_f in kilometers, is determined from the equivalent of Equation (7), page 1031, of Briggs (1971), and the assumption that the distance to final rise is 3.5 x*, where x* is the distance at which atmospheric turbulence begins to dominate entrainment.

For F less than 55:

$$x_f = 0.049\ F^{5/8}$$

For F equal to or greater than 55:

$$x_f = 0.119\ F^{2/5}$$

The plume height, H, in meters, is determined from the equivalent of the combination of Equations (6) and (7), page 1031 of Briggs (1971):

For F less than 55:

$$H = h' + 21.425\ F^{3/4} / u(h)$$

For F equal to or greater than 55:

$$H = h' + 38.71\ F^{3/5} / u(h)$$

Unstable or Neutral —— Momentum Rise

For situations where the stack gas temperature is less than or equal to the ambient air temperature, the assumption is made that the plume rise is

dominated by momentum. If ΔT is less than $(\Delta T)_c$, the assumption is also made that the plume rise is dominated by momentum. The plume height is calculated from Equation (5.2), page 59 of Briggs (1969):

$$H = h' + 3d\ v_s/u(h)$$

Briggs (1969) suggests on page 59 that this equation is most applicable when v_s/u is greater than 4. Since momentum rise occurs quite close to the point of release, the distance to final rise is set equal to zero.

Stable —— Crossover between Momentum and Buoyancy

For stable situations the stability parameter s is calculated from the equation on page 1031 of Briggs (1971):

$$s = g\frac{\partial\theta/\partial z}{T}$$

As an approximation, for stability class E, or 5, $\partial\theta/\partial z$ is taken as 0.02 K m^{-1}, and for stability class F, or 6, $\partial\theta/\partial z$ is taken as 0.035 K m^{-1}.

For cases with stack gas temperatures greater than ambient air temperature, it is necessary to determine whether the plume rise is dominated by momentum or buoyancy. The crossover temperature difference $(\Delta T)_c$ is found by setting Equation (59), page 96 of Briggs (1975) equal to Equation (4.28), page 59 of Briggs (1969) and solving for ΔT. The result is:

$$(\Delta T)_c = 0.01958\ T\ v_s\ s^{1/2}$$

If the difference between stack gas temperature and ambient air temperature, ΔT, exceeds the $(\Delta T)_c$, the plume rise is assumed to be buoyancy dominated; if less than this amount, the plume rise is assumed to be momentum dominated.

Stable —— Buoyancy Rise

For situations where ΔT exceeds $(\Delta T)_c$ as determined above, buoyancy is assumed to dominate. The distance to final rise, in kilometers, is determined by the equivalent of a combination of Equations (48) and (59), page 96, in Briggs (1975):

$$x_f = 0.00207\ u(h)\ s^{-1/2}$$

The plume height is determined by the equivalent of Equation (59), page 96 of Briggs (1975):

$$H = h' + 2.6\left(\frac{F}{u(h)s}\right)^{1/3}$$

Stable —— Momentum Rise

Where the stack gas temperature is less than or equal to the ambient air temperature, the assumption is made that the plume rise is dominated by momentum. If ΔT is less than $(\Delta T)_c$, the assumption is also made that the plume rise is dominated by momentum. The plume height is calculated from Equation (4.28), page 59, of Briggs (1969):

$$H = h' + 1.5\left(\frac{v_s^2 d^2 T}{4T_s u(h)}\right)^{1/3} s^{-1/6}$$

The equation for unstable-neutral momentum rise is also evaluated. The lower result of these two equations is used as the resulting plume height.

All Conditions —— Distance Less Than Distance to Final Rise

For unstable, neutral, or stable conditions, if the distance upwind from receptor to source x, in kilometers, is less than the distance to final rise, the equivalent of Equation (2), page 1030 of Briggs (1972) is used to determine plume height:

$$H = h' + \frac{160.\ F^{1/3}\ x^{2/3}}{u(h)}$$

This will be used only for buoyancy dominated conditions. Should this value exceed the final rise for the appropriate condition, the final rise is substituted instead.

General

In working through the receptors to determine concentrations for a given hour, the first time a source is found to lie upwind of a receptor the following quantities are determined and stored for that source: u(h), h', F, H,

and x_f. These quantities are then used each time this source is encountered during this hour without recalculation. Only if the upwind receptor-source distance is less than x_f, the effective plume height is determined for each occurrence by the last mentioned equation.

EFFLUENT RISE FOR AREA SOURCES

RAM can include changes in effective height with wind speed for area sources. The input area source height H_A is assumed to be the average physical height of the area source plus the effluent rise with a wind speed of 5 m s^{-1}. The user specifies the fraction f of the input height that represents the physical height, h_p. This fraction is the same for all area sources in the inventory.

$$h_p = f\, H_A \quad .$$

The difference is the effluent rise for a wind speed of 5 m s^{-1}.

$$\Delta H\ (u = 5) = H_A - h_p \quad .$$

If f = 1, there is no rise and the input height is the effective height for all wind speeds. For any wind speed u the rise is assumed to be inversely proportional to wind speed and is determined from:

$$\Delta H\ (u) = \frac{5(H_A - h_p)}{u} \ ,$$

and the effective height is:

$$H_e\ (u) = h_p + \Delta H(u) \quad .$$

CONCENTRATIONS FROM POINT SOURCES

The upwind distance x of the point source from the receptor and the crosswind distance, y, of the point source from the receptor are calculated as part of estimates for each source-receptor pair for each simulated hour. Both dispersion parameter values σ_y and σ_z are determined as functions of this upwind distance x and stability class.

One of three equations is used to estimate concentrations under various conditions of stability and mixing height. Equation (A3) in the Appendix is used for stable conditions or for unlimited mixing. In this equation,

eddy reflection at the ground is assumed. For unstable or neutral conditions where vertical dispersion is great enough that uniform mixing is assured beneath an elevated inversion, Equation (A4) in the Appendix is used. For unstable or neutral conditions where vertical dispersion is still small compared to the mixing height, Equation (A5) in the Appendix is used, which incorporates multiple eddy reflections from the ground and the base of the stable layer aloft. The simplifications to the above mentioned equations, which occur if the height of the receptor z is assumed at ground-level, are incorporated into RAM.

CONCENTRATIONS FROM AREA SOURCES

The total concentration at a receptor from the two-dimensional area source distribution is calculated using the narrow plume simplification discussed by Gifford and Hanna (1971). This simplification is assumed because the upwind zone of influence affecting a receptor (an upwind oriented point source plume) is normally quite narrow in comparison with the characteristic length scale for appreciable changes in the magnitude of the area-source emission rate itself. Under these circumstances the two-dimensional integral that expresses the total area-source contribution to concentration at a receptor can be replaced approximately by a one-dimensional integral. This integral involves only two things: 1) knowledge of the distribution of the area-source emission rates along the line in the direction of the upwind azimuth from the receptor location, and 2) the meteorologically dependent function that specifies the crosswind-integrated concentration in the Gaussian plume from a point source. In using this area source technique, Gifford and Hanna assumed area source emissions at ground level allowing integration upwind to be accomplished analytically. In RAM the area sources are considered to have an effective height, requiring the integration to be accomplished numerically. Equations used to perform the calculations are given in the Appendix. Internal tables of integrations for one to three effective area source heights are calculated at the beginning of each simulated hour using the specific meteorological conditions for that hour. The total concentration from all area sources is determined by performing the integration piecewise over each source in the upwind direction from the receptor until the farthest boundary of the source region is reached.

4. ORGANIZATION OF COMPUTER PROGRAMS

INTERRELATIONSHIP OF EIGHT MAIN PROGRAMS

The eight main programs in the RAM system consist of the four versions of RAM: RAM, RAMR, RAMF, and RAMFR; three preprocessor programs: RAMQ, RAMMET, and RAMBLK; and one postrun processor: CUMF. The relationships are shown in Figure 1.

The four versions of RAM are similar, but their differences can be categorized by the following 2 by 2 matrix.

	NORMAL RAM	FREQUENCY DISTRIBUTION RAM
URBAN σ's	RAM	RAMF
RURAL σ's	RAMR	RAMFR

Two of the versions (RAM and RAMF) have dispersion parameters, σ, representative of urban areas. These σ's are based upon the tracer experiments performed in St. Louis and reported by McElroy and Pooler (1968) and are most representative for z_0 of about 1 m. The equations used to represent these σ values are those of Briggs as reported in Gifford (1976). The urban σ's are functions of distance between source and receptor, and of atmospheric stability class where the class is specified by open country conditions.

The other two versions (RAMR and RAMFR) are for rural conditions and utilize the dispersion parameter values of Pasquill-Gifford (Pasquill, 1961; Gifford, 1960) representative for z_0 of about 0.03 m as used in the UNAMAP programs PTMAX, PTDIS, and PTMTP. These values are equivalent to the disper-

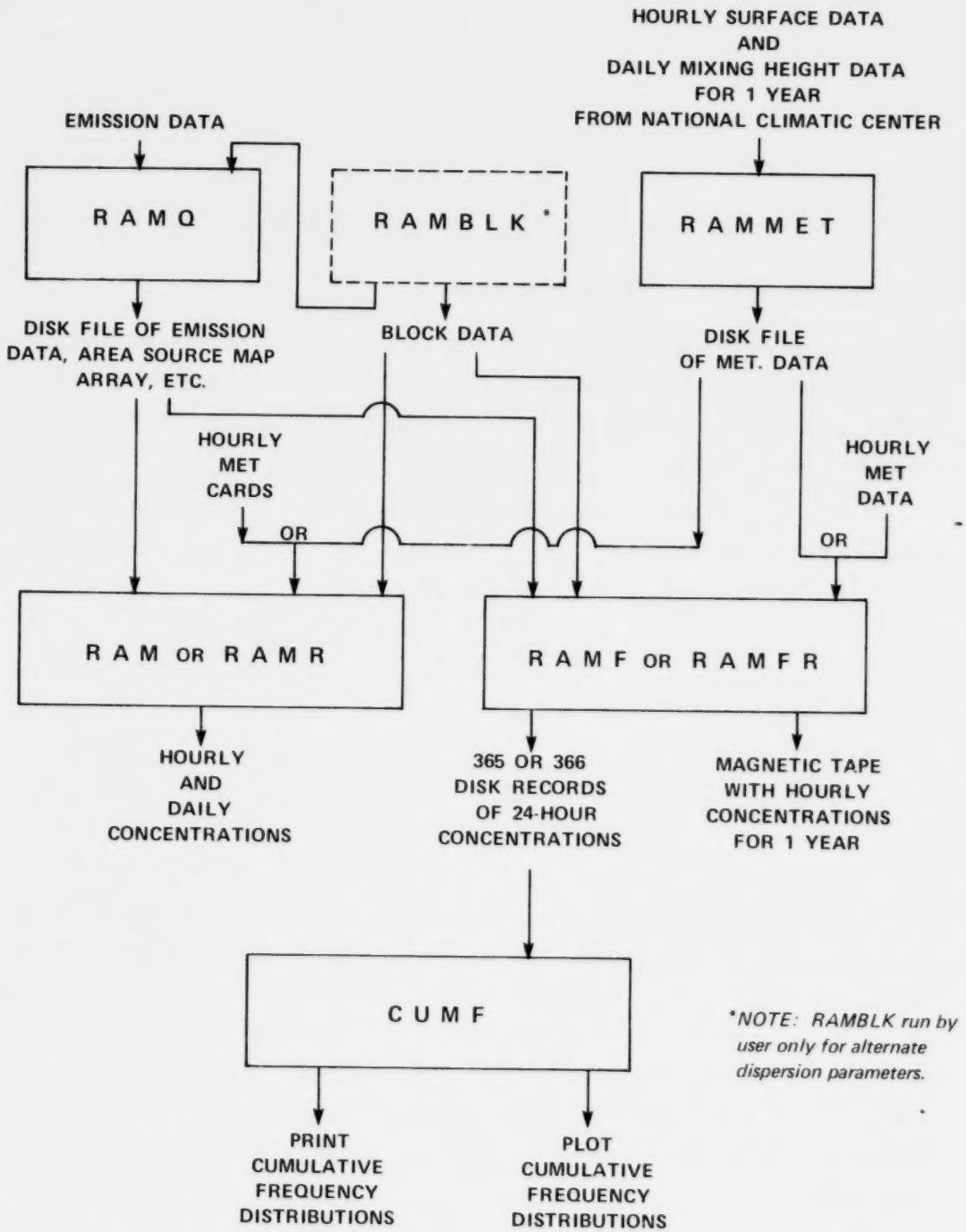

Figure 1. Interrelationships of RAM system main programs

sion parameter values given in Figures 3-2 and 3-3 of the Workbook of Atmospheric Dispersion Estimates (Turner, 1970), and may be revised in the future according to Pasquill and Smith (Pasquill, 1974) in order to include effects of surface roughness.

Looking at the other dimension of the matrix, the normal RAM is intended for application to one or several days but not for long periods of record. These versions have a full range of options available to the user.

The RAMF and RAMFR versions calculate frequency distributions of concentrations for a full year's data; therefore, to insure some degree of efficiency, most of the options of RAM are not available. For this version the receptor coordinates must be specified by the user at the beginning of the run to insure that frequency distributions of concentrations are for a fixed set of receptor locations.

The RAM system has four other main programs in addition to the four versions of RAM. Figure 1 shows the interrelationships of these four programs to the four versions of RAM.

RAMBLK is executed to produce BLOCK DATA for the RAM programs, which help determine distance to maximum concentration. Several subroutines are called including appropriate subroutines to determine dispersion parameter values as functions of stability class and source-receptor distance. The data produced are coefficients and exponents for the various ranges of effective height of emission and are used to determine maximum $\chi u/Q$ (relative concentration normalized for wind speed) for point sources and distance to maximum concentration for point and area sources as functions of stability class and effective height of emission. This program is executed for each given method of determining dispersion parameter values σ_y and σ_z. Therefore, RAMBLK was executed once using the subroutines for urban dispersion parameters to produce BLOCK DATA for RAM and RAMF. RAMBLK uses the same subroutines as RAM. RAMBLK was executed a second time using the subroutines for rural dispersion parameters to produce BLOCK DATA for RAMR and RAMFR. Both of these outputs from RAMBLK -- urban parameters and rural parameters -- are used in RAMQ. However, unless the user needs to modify one of the RAM models in order to use some other system of dispersion parameters, there is

no need to execute RAMBLK since the outputs of RAMBLK are already incorporated in the RAM versions as a result of the initial executions of RAMBLK.

RAMQ processes emission data for all four versions of RAM. Its principal task is to set up the area source map array. The area source map array provides a correspondence between locations (referred to by coordinates) and area source number. Other tasks such as ranking sources according to set criteria are also accomplished.

If meteorological data, including hourly mixing height, are entered into any of the versions of RAM with data for each hour on a card, RAMMET is not used. If a period of record of hourly surface data from the National Climatic Center in card image format is being used, RAMMET is executed. Input consists of both 1) one year's surface data in the form of one observation per hour, and 2) one maximum and one minimum mixing height per day. The program primarily determines hourly stability and interpolates to obtain estimates of hourly mixing height. The output data are organized so that a single disk record is produced for each day. Output from RAMMET may be used as input to any of the versions of RAM.

The remaining main program in the RAM system is CUMF. Although RAMF and RAMFR can be run for a number of sampling times, CUMF is used with disk output for runs of RAMF or RAMFR for 24-hour sampling times to determine cumulative frequency distributions for the 24-hour concentrations for each receptor location. A table for each receptor is produced ranking the 24-hour concentrations for the year. The program also utilizes a Cal-Comp plotter to produce cumulative frequency plots of estimated concentrations. The plot for each receptor is concentration on a log scale versus frequency on a probability scale.

BRIEF DESCRIPTIONS OF PROGRAMS

The interrelationships of the eight main programs are shown in Figure 1. Brief descriptions of these main programs follow:

RAMBLK - This main program determines $\chi u/Q$ maxima and distance to the point of maximum for point sources as functions of stability class and effective height of emissions. Coefficients and exponents relating

these two parameters to effective height of emission are determined for various stability and effective height range combinations. These coefficients and exponents as well as ones for determining the distance of the maximum concentration downwind from the edge of an area source are output from this program in the form of punch cards to be used as block data in RAMQ and the four versions of RAM. The subroutines DBTRCB and JMHCZB, which are similar to subroutines DBTRCU and JMHCZU in RAM, are used for estimation of maximum concentration. In order to produce the block data, BLOCK, for urban areas, RAMBLK calls the subroutines BRSYSZ and BRSZ for calculation of urban dispersion parameters. And similarly, in order to produce the block data, BLOCKR, for open countryside, RAMBLK calls the subroutines PGSYSZ and PGSZ for calculation of rural dispersion parameters.

RAMQ - This program primarily processes emission inventory information so that it can be used later in any of the four RAM versions. An important aspect of this is the construction of the area source map array which allows a correspondence between any location in the area source region and the number of the area source at that location. All source coordinates in units convenient to the user (user units) are converted to internal units. An internal unit is a length such that any area source side length used in a given run can be expressed as an integer multiple of an internal unit. The internal unit is generally equal to the length of the side of the smallest area in the emission inventory. The user must determine the internal unit length and specify it in user units. Both point and area sources are ranked according to expected impact at ground level. The 25 point sources and the 10 area sources with the greatest expected ground-level impact are listed. Also, the total emissions from various physical heights for both point and area sources are listed. This aids the user in determining area source heights and the number to be used. Generated information is placed on disk files to be used as input to the RAM programs. RAMQ requires BLOCK, the data generated by RAMBLK for urban areas,

and BLOCKR, the data generated by RAMBLK for open countryside. RAMQ output is required as input to all four versions of RAM.

RAMMET - This program processes meteorological data for one year. The data input consists of hourly meteorological records in the standard card format 144 of the National Climatic Center and twice-a-day estimates of mixing height (minimum and maximum). Hourly stability class is determined using the objective method of Turner (1964) based on Pasquill's technique (Pasquill, 1961). Shifts by only one stability class are allowed for adjacent hours. Hourly mixing height is interpolated from the twice-a-day estimates. Hourly meteorological data of wind direction, wind speed, temperature, stability class, and mixing height are written into a file with one record per day for the entire year. The subroutine RANDU which generates random numbers is called by RAMMET. RANDU is a library subroutine of UNIVAC 1110's MATH-PACK. (For use on other computers this call must be replaced by a call to a suitable random number generator, or, to be consistent with outputs generated by EPA test data, use the set of random numbers furnished in the CRSTER file of UNAMAP.) Meteorological data may be input into the RAM versions either as the output from RAMMET or as card input, one card per hour. (Data files produced by RAMMET are also compatible as input to two other dispersion programs MX24SP and CRSTER. These are not directly related to RAM.)

RAM - This short-term Gaussian steady-state model estimates concentrations of stable pollutants from urban point and area sources. The general structure of RAM and the subroutines called by RAM (and the rural version RAMR) are given in Figure 2. Hourly meteorological data are required. Hourly concentrations and averages over an averaging time less than or equal to 24 hours can be estimated. RAM is normally not executed for a time period exceeding several days. Briggs plume rise is used. Pasquill-Gifford dispersion equations with dispersion parameters considered valid for urban areas are used in the model. Concentrations from area sources are determined using the narrow plume hypothesis; that is, sources

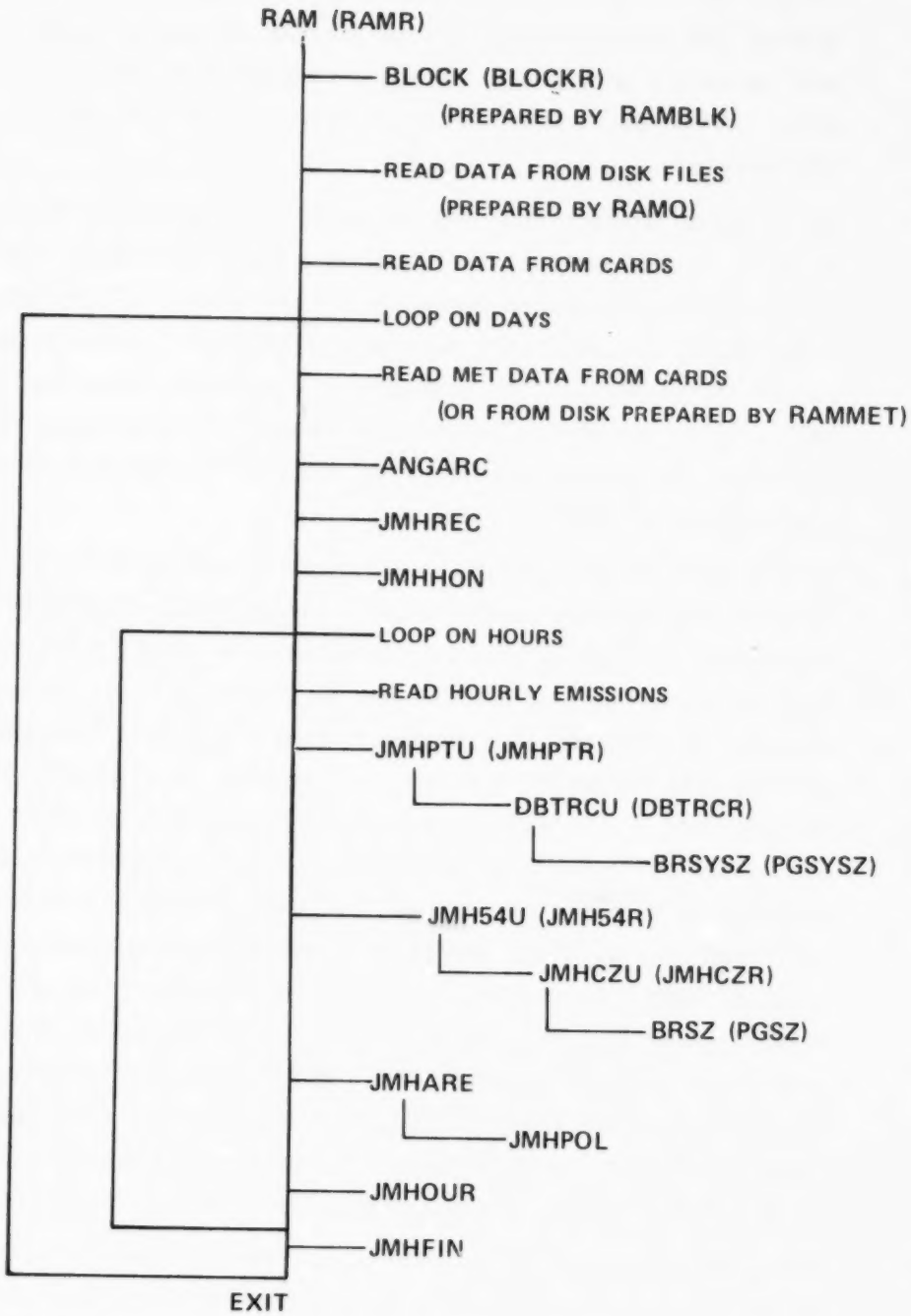

Figure 2. Subroutine structure of RAM and RAMR

directly upwind are considered representative of area source emissions affecting the receptor. Special features of the model include determination of receptor locations downwind of significant sources and determination of locations of uniformly spaced receptors to ensure good area coverage with a minimum number of receptors. RAM allows use of 250 point sources, 100 area sources, and 150 receptors.

RAMR - This program differs from RAM in that it is applicable for locations in basically rural surroundings. Because of this the Pasquill-Gifford dispersion parameter values are used. The subroutines PGSYSZ and PGSZ will duplicate values of σ_y and σ_z from the curves in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970). Also the mixing heights generated for rural areas by RAMMET are used. In general no area sources would be expected for most applications of RAMR.

RAMF - This program is designed to allow computations for a full year of record. The general structure of RAMF and RAMFR along with the subroutines called by these two programs are given in Figure 3. Many of the options of RAM are not available in this version because the receptor locations must remain the same from period to period. All receptor locations must be read in as input; none can be generated. This is to prevent changing receptor locations from day to day as in RAM when using the option to generate receptors downwind of significant sources. Although computations are performed hour-by-hour, emphasis is upon averaging times longer than one hour. Only output for the selected averaging time is printed (note that only output for a 24-hour averaging time is compatible with the program CUMF, see below.) However, hourly concentrations and averages for the averaging time selected for each receptor are transferred to a magnetic tape and can be processed by the user to yield averages for other time periods.

RAMFR - This program is similar to RAMF but differs in that dispersion parameter values and mixing heights representative for rural areas

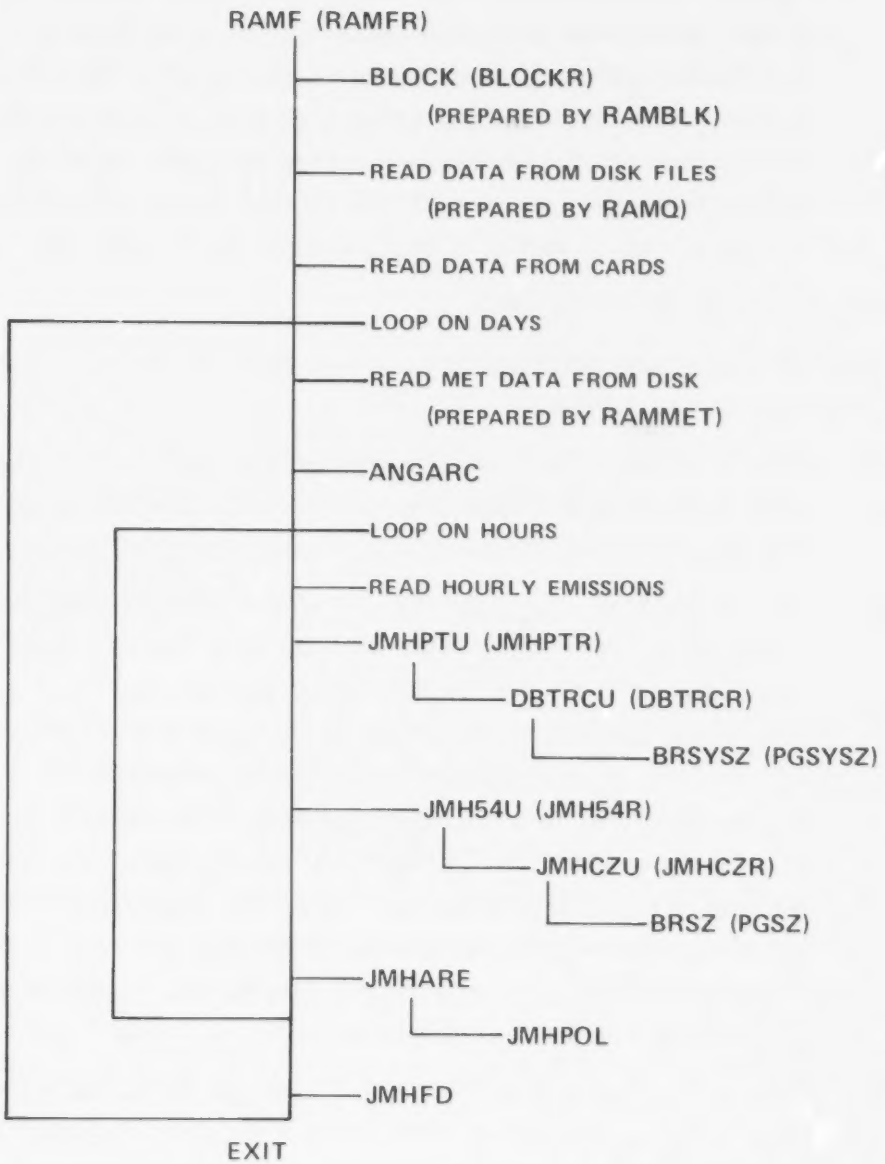

Figure 3. Subroutine structure of RAMF and RAMFR

are used. This program should be applied only to sources in rural surroundings.

CUMF - This program uses disk output from RAMF or RAMFR to print and plot cumulative frequency distributions of 24-hour concentrations over the one-year period for each receptor. Print-out consists of ranking concentrations from lowest to highest with Julian day number associated with each concentration also printed. The annual arithmetic average concentration is also given. The plot is log of concentration against cumulative frequency on a probability scale. Subroutines GRAPH and PROB are called by CUMF. Also the following subroutines that are part of the CALCOMP Basic Software package are called by CUMF: PLOTS, SYMBOL, NUMBER, PLOT, and LINE.

BRIEF DESCRIPTIONS OF SUBROUTINES

The subroutine and function descriptions that follow are in the order in which they are called by RAM.

ANGARC - This function determines the appropriate arctan of the east resultant wind component over the north resultant wind component with the resulting angle between 0° and 360°.

JMHREC - This subroutine called by RAM and RAMR determines receptor locations downwind of significant sources based upon the resultant meteorological conditions for the averaging period, usually 3 or 24 hours. Plume rise and effective height of emission are calculated. The distance of the maximum concentration is determined as a function of the stability and the effective height of emission in order to locate the position of a receptor. Two receptors are generated for each significant point source, one at the expected distance of maximum concentration and one at twice this distance. One receptor is generated for each significant area source at the expected distance of maximum concentration.

JMHHON - This subroutine called by RAM and RAMR generates additional receptors within a specified area in order to give adequate coverage of that area with the minimum number of receptors. Receptors are placed equidistant from nearby receptors resulting in a honeycomb

array. The distance between receptors is an input to the main program. Proposed receptors located closer than half this distance to any other receptor are not included.

JMH54U - This subroutine called by RAM and RAMF generates tables of $\chi u/q_A$ (relative concentration normalized for wind speed) from area sources that extend from a receptor to various upwind distances. A table is produced for each area source height. One to three heights can be used. This subroutine calls subroutine JMHCZU which performs the urban dispersion calculation obtaining σ_z from BRSZ.

JMH54R - This subroutine called by RAMR and RAMFR is similar to JMH54U except that it calls JMHCZR which calls PGSZ to determine rural dispersion parameter values.

JMHCZU - This subroutine called by JMH54U calculates concentrations from infinite crosswind line sources at a distance x upwind from a receptor. To obtain the vertical dispersion parameter value σ_z, subroutine BRSZ is called.

JMHCZR - This subroutine called by JMH54R is similar to JMHCZU except that rural dispersion parameter values are determined from PGSZ.

JMHCZB - This subroutine called by RAMBLK uses subroutines for both urban and rural dispersion parameters, BRSZ and PGSZ.

BRSZ - This subroutine called by JMHCZU in RAM and RAMF determines the value of the vertical dispersion parameter σ_z for a given upwind distance of receptor to source. The parameter values are for urban areas from the experiments of McElroy and Pooler (1968).

PGSZ - This subroutine called by JMHCZR in RAMR and RAMFR determines the value of the vertical dispersion parameter σ_z for a given upwind distance of receptor to source. The parameter values are for rural areas and are the same as those given in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970).

JMHARE - This subroutine called by all four versions of RAM integrates along the line upwind from the receptor in order to obtain the effect of all area sources along this line. This is accomplished by finding

the closest and farthest distance of each source along this path and calling the subroutine JMHPOL for each distance. JHMPOL interpolates between values in the tables generated by JMH54U or JMH54R in order to obtain the effect of area sources to the specific distance.

JMHPOL - This subroutine called by JMHARE interpolates for a given distance from the values in the tables generated by subroutine JMH54U or JMH54R. This yields the effect of an area source at the given height extending upwind to this distance.

JMHPTU - This subroutine is called by RAM and RAMF to determine concentrations at receptors from point sources in urban areas. Subroutine DBTRCU and the dispersion parameter routine BRSYSZ are called to complete the computations.

JMHPTR - This subroutine called by RAMR and RAMFR determines concentrations at receptors from point sources in rural areas. Subroutine DBTRCR and the dispersion parameter routine PGSYSZ are called to complete the computations.

DBTRCU - This subroutine is called by JMHPTU to determine the relative concentration at a receptor from a point source in an urban area at a given upwind and crosswind distance. This subroutine calls BRSYSZ.

DBTRCR - This subroutine is called by JMHPTR to determine the relative concentration at a receptor from a point source in a rural area at a given upwind and crosswind distance. This subroutine calls PGSYSZ.

DBTRCB - This subroutine is called by RAMBLK to determine the relative concentration at a receptor from a point source in either rural or urban surroundings. This subroutine calls BRSYSZ and PGSYSZ.

BRSYSZ - This subroutine called by DBTRCU of RAM and RAMF, determines the values of σ_y and σ_z for a given upwind distance of source to receptor. The parameter values are for urban areas.

PGSYSZ - This subroutine called by DBTRCR of RAMR and RAMFR determines the values of σ_y and σ_z for a given upwind distance of source to receptor. The parameter values are for rural areas.

JMHOUR - This subroutine called by RAM and RAMR writes hourly output.

JMHFIN - This subroutine called by RAM and RAMR produces output for the basic averaging time, usually 24 hours.

JMHFD - This subroutine called by RAMF and RAMFR is very similar to JMHFIN but also writes concentrations for the selected averaging time to disk for further processing by CUMF.

GRAPH - This subroutine called by CUMF uses the plotter to draw the base chart for the plot of log of concentration against probability. The following subroutines that are part of the CALCOMP Basic Software package are called by GRAPH: PLOT, SYMBOL, and NUMBER. Also; subroutine LGAXS, which is part of the Scientific Applications Category of CALCOMP's Functional Software Library, is also called by GRAPH.

PROB - This function called by CUMF determines plotting position on the probability scale.

5. DATA REQUIREMENTS

This chapter is intended to show the user the general data requirements for the RAM programs.

RAMBLK

The program RAMBLK requires input of a single digit (1 if data for rural areas are to be generated, or 2 if data for urban areas are to be generated). Four subroutines are called, two (one for urban, one for rural) that determine both dispersion parameter values σ_y and σ_z as functions of stability class and source-receptor distance, and the other two (one for urban, one for rural) that determine σ_z only.

If a user finds it necessary to run RAMBLK (because of a need to use dispersion coefficients not routine in RAM), it will be necessary to closely follow the instructions on modification of the output in order for it to be compatible with RAMQ. Specific instructions are given in section 10 of Vol. II.

RAMQ

Program RAMQ processes the emissions. Either point sources, or area sources, or both types may be included. When both types of sources are included in the output from RAMQ, the user still has the option in RAM to select one or both source types. Most any rectangular coordinate system can be used provided that the positive quadrant is used, that is, that all coordinate values are positive and a single coordinate system is used for both point and area sources. The scale of the coordinate system is completely arbitrary. The input is as follows (variable names and card formats are given in explanatory material with the RAMQ runstream example).

RAMQ-CARD 1 Up to 80 alphanumeric characters for a title.

RAMQ-CARD 2 - 4 variables

a) Estimated number of point sources (this must be set to zero if the run is for area sources only.)

b) Estimated number of area sources (this must be set to zero if the run is for point sources only.)

c) Pollutant-indicator (3 is used for SO_2, and 4 for suspended particulate).

d) Dispersion parameter indicator (1 is used for rural, and 2 for urban).

RAMQ-CARD 3 - 2 variables

a) Number of user units per internal unit. (An internal unit is a length such that any area source side length in this run is a multiple of the internal unit.)

b) Multiplier constant to convert length in user units to kilometers (for example, if the user units are in miles, this constant would be 1.609344).

RAMQ-CARD TYPE 4 - 9 variables (one of these cards for each point source).

a) Point Source Identification (12 characters)

b) East Coordinate (user units)

c) North Coordinate (user units)

d) SO_2 Emission Rate (grams/second)*

e) Particulate Emission Rate (grams/second)*

f) Physical Stack Height (meters)

g) Stack Gas Exit Temperature (K)

h) Stack Inside Diameter (meters)

j) Stack Gas Exit Velocity (meters/second).

To indicate the end of point source cards, the words "END POINTS" are punched in card columns 1 to 10.

---

*Emission rates for other pollutants may be substituted for sulfur dioxide and particulates. If substitutions are made, changes in data statements are necessary in order to have the proper pollutant names on printed output.

RAMQ-CARD TYPE 5 - 6 variables (one of these cards for each area source).

a) East coordinate of Southwest Corner (user units)

b) North Coordinate of Southwest Corner (user units)

c) Area Source Side Length (user units)

d) SO_2 Emission Rate (grams/second)**

e) Particulate Emission Rate (grams/second)**

f) Height of Emission (meters)

Although only one pollutant can be considered for a given run of either RAMQ or any of the versions of RAM, both of the entered emission rates are listed on RAMQ output. One of the emission rates may be left off and will appear as zeros on the output.

Area sources can vary in size, but certain requirements must be met. There must be a definable internal unit such that the side length of all other area sources is an integer multiple of the side length of this internal unit. For example, if an emission inventory consists of area source squares having side lengths of 1, 2.5, 5, and 10 km, the internal unit must be chosen to equal 0.5 km. It is better to conduct emission inventories so that area source squares have side lengths that are multiples of the side lengths of the smallest area source squares. Also if a grid is constructed of UNIT SQUARES, squares having side length of one internal unit, the boundaries of all area sources must coincide with lines in that grid; there can be no overlap of one area source over another. Although these statements may seem restrictive, the area source entries to RAMQ are quite versatile. Concentrations from area sources are calculated by performing computations for each area source encountered in proceeding from a receptor in the upwind direction until the upwind boundary of the area sources is encountered. If there are large areas (larger than the UNIT SQUARE) of zero emissions within the rectangle that includes all area sources (area source region), it is desirable to define these as area sources with zero emissions in squares as

---

**The emission rate is a total rate for the entire area. It is later transformed into g $s^{-1}m^{-2}$. As with point sources, emission rates for other pollutants may be substituted for sulfur dioxide, and particulates with appropriate name changes made in data statements to affect titles on printout.

large as is possible. This will save considerably in computer running time. For further clarification on area sources, see p. A-2 in the Appendix.

If the height of emission is the effective height of the area source at a wind speed of 5 m s^{-1}, and if the physical height of the source is a set fraction of this value, which is the same for all area sources, it will be possible to consider the variation of effective height of area sources with wind speed in RAM. Otherwise the fraction will be 1.0, and it will be assumed that the input height of emission is the effective height for all wind speeds.

METEOROLOGICAL DATA AND RAMMET

Meteorological data for all four versions of RAM can be furnished in either of two ways: 1) punched cards containing the meteorological data for each simulated hour (one punch card per hour), or 2) magnetic disk or tape output from the program RAMMET.

Meteorological data output from the program RAMMET may be used as input to all four RAM versions. RAMMET requires one year of hourly surface observation data and one year plus two days of daily maximum and minimum mixing height data. The hourly surface data normally on magnetic tape in card image format, CARD DECK 144, can be obtained from the National Climatic Center in Asheville, N.C.

All required surface data for each hour must be included on the tape; therefore, all data flagged as missing by RAMMET must be determined and included in the data set before proceeding. The data used from the surface observation tape for each hour are: Year, Month, Day, Hour, Cloud Ceiling Code, Wind Direction, Wind Speed, Temperature, and Opaque Cloud Cover.

The mixing height data is expected in card format, one card per day containing the minimum and maximum mixing height for that day.

A more detailed description of required data follows, but variable names and card formats are given with the RAMMET example run stream.

RAMMET-CARD 1 - 7 variables

a) A 5-digit identification of the meteorological tape to be used. For tapes generated by the National Climatic Center, this will normally be the surface station number.

b) A two-digit year of the meteorological data.

c) The latitude (degrees) of the site to be modeled.

d) The longitude (degrees) of the site to be modeled (positive for west longitude, negative for east longitude).

e) The time zone of the site equivalent to the Greenwich Meridan Time minus the local standard time.

f) The number of days to be processed (the same as the number of days in the year).

g) An initial number to be used as the beginning point for the random number generator. If the same initial number is used, the same set of random numbers will be generated each time the program is run. Any odd numbers greater than three digits are suggested as appropriate seeds.

RAMMET-CARD 2 - 2 variables

a) Yesterday's minimum mixing height (meters).

b) Yesterday's maximum mixing height (meters).

This card will contain data for December 31 of the previous year. The mixing heights will normally be determined using the methods of Holzworth (1972). The maximum mixing height is used for both urban and rural applications. The minimum mixing height is used only for urban applications.

RAMMET-CARD 3 - 4 variables

a) Identification for the radiosonde station used to determine the mixing height.

b) A 2 digit year for the mixing height data.

c) Minimum mixing height (meters).

d) Maximum mixing height (meters).

This card will contain data for January 1.

RAMMET-CARD TYPE 4 - 2 variables

a) Minimum mixing height (meters).

b) Maximum mixing height (meters).

There will be as many type 4 cards as the number of days in the year, and data will be for January 2 through January 1 of the next year.

RAM and RAMR

In addition to requiring emission information from RAMQ and accepting meteorological information from either punch cards or a file generated by RAMMET, RAM and RAMR require some punch card input. This is described and commented upon.

RAM-CARDS 1 - 3. Each card has up to 80 alphanumeric characters.

Information is written on all output and can suit the user. Normal use has been to identify the user and the run date on card 1, the location and date of the emissions data on card 2, and the locations and dates of both surface and upper air meteorological data on card 3.

RAM-CARD 4 - 9 variables, 22 values

a) Values for 13 different options, 1 is used to employ the option, 0 is for nonuse.

Option 1 - used if computations are to be performed for point sources.

Option 2 - used if computations are to be performed for area sources.

Option 3 - used to indicate that permanent receptor coordinates will be entered.

Option 4 - used if receptors downwind of significant point sources are to be generated.

Option 5 - used if receptors downwind of significant area sources are to be generated.

Option 6 - used if receptors (referred to as honeycomb receptors) are to be generated by the program in order to insure good area coverage. Receptors generated under this option are placed equidistant in staggered rows over a specified area.

Candidate receptor positions are checked against other receptors (either input or generated by other options of the program) and if the distance between the proposed receptor and any other receptor is less than one-half the normal distance between honeycomb receptors, then that candidate receptor is not added to the list. The boundaries of the area to be covered by these receptors are specified by the user using card type 11.

Option 7 - used if hourly output is desired by the user. If not employed, output will occur for the specified averaging time, normally from 3 to 24 hours.

Option 8 - used if partial concentrations are to be written on disk. Partial concentrations are the individual concentration contributions due to each source at each receptor. This option should be used with a recognition for the tremendous quantities of data which will be generated.

Option 9 - used if hourly summaries are to be printed rather than the entire hourly output. This results in one page of printed output instead of three or more pages for each hour. Used only if option 7 is used.

Option 10 - used if cards containing concentrations for each receptor location for the averaging time selected are to be punched. These cards can be used externally such as with the CALCOMP contouring routines.

Option 11 - used if meteorological data is input on cards with one card for each simulated hour (see card type 12.)

Option 12 - used if the user will specify source numbers (from the input emission list) that he wants to consider as significant. This will allow the examination of the individual contributions to each receptor from each of the specified sources. Both point and area sources may be specified (see card types 6 and 9.)

Option 13 - used if emissions will be read hourly. This is the preferred method of operation of RAM since it allows consideration of all known variability in emission rates. The exit

velocity is scaled according to the varying emission rates during program execution in order to allow for an appropriate plume rise calculation.

b) The number of periods to be run. For example, if the run will use data for 2 days (48 hours) and the averaging time is to be 3 hours, the number of periods will be 16.

c) The number of hours in the averaging time ($\leq$ 24). If the averaging time is 24 hours, the number of periods is equivalent to the number of days to be run. For averaging times of 1, 2, 3, 4, 6, 8, 12, or 24 hours, any number of periods may be run. For averaging times other than those specified above, the total number of hours run cannot exceed 24 hours.

d) Receptor height above ground (meters). All receptors must be at the same height for a given run.

e) Pollutant half-life (seconds).

f) The number of significant point sources (maximum of 25).

g) The number of significant area sources (maximum of 10).

h) A 2-digit year and a 3-digit starting Julian day for this run.

i) The start hour for this run.

When using meteorological data from RAMMET, there are greater restrictions on certain input parameters than there are when meteorological data from cards are used. Using RAMMET data, one averaging time must be used, and it must be evenly divisible into 24. The start hour must be 1. Periods must be sequential in the time series. The starting day may be any in the file. The file will be positioned to the correct start day based upon the Julian day entered on card 4.

When using meteorological data from cards, one averaging time must be used, but it can be any integer value from 1 to 24. The start hour can be any hour from 1 to 24. Day and hour values must be punched correctly on input cards and must be in sequence within each period. Data from period to period need not be in sequence. For example, calculations for two two-hour periods could be made for first: day 181, hour 24, followed by day 182, hour 1, then secondly: day 23, hour 13, followed by day 23, hour 14.

RAM-CARD TYPE 5 - 4 variables. This card is required only if option 11 is not used, meaning that meteorological data from RAMMET will be used.

a) Surface meteorological station identification - (normally 5 digits)

b) Year of surface data - 2 digits.

c) Identification of radiosonde station used to determine mixing height.

d) Year of mixing height data - 2 digits.

RAM-CARD TYPE 6 - 2 variables - from 2 to 26 values

This card is required only if both options 1 and 12 are used.

a) The number of user specified significant point sources (maximum of 25).

b) The point source numbers that the user wants to consider significant. There will be as many sources in this list as indicated in a).

RAM-CARD TYPE 7 - 4 variables - 4 to 6 values.

This card is required only if option 2 is employed (area sources).

a) Fraction of area source height that is physical height (1.00 or less).

b) Distance limit for integration of the area source contribution (user units). The distance should be equal to or exceed the greatest possible distance from a receptor (including receptors generated by RAM) to the farthest corner of the area source region for this run.

c) Number of heights to be used for area sources (from 1 to 3).

d) Height(s) in meters for the area source integrations. There must be as many heights as specified by the previous variable. Look at RAMQ output to help decide on these heights.

RAM-CARD TYPE 8 - 1 variable - 1 or 2 values

Heights between the area source height classes. One value is read if the number of heights on the previous card is one or two. If only one area source height is to be used (1 entered in c, and one value in d of card Type 7), the height read here must have a value higher than any area source height in the data set for this run.

Two values are read if the number of heights on the previous card is three. These heights are to distinguish between area height classes and can be chosen by examining the output from RAMQ to determine the quantities of area source emissions that are released from various height ranges.

RAM-CARD TYPE 9 - 2 variables - 1 to 11 values

This card is required only if options 2 and 12 are used.

a) The number of user specified significant area sources (maximum of 10).

b) The area source numbers that user wants to consider significant. There will be as many sources in this list as indicated in a).

RAM-CARD TYPE 10 - 3 variables

If option 3 is used there will be one card for each receptor that the user specifies.

a) Receptor identifier in eight alphanumeric characters.

b) East coordinate of receptor in user units.

c) North coordinate of receptor in user units.

Both coordinates of receptors should be positive. Receptors may be either inside or outside the area source region. A blank card signals that the receptor list has been completed. Therefore, a receptor at the origin cannot be used since it would cause the same program flow as a blank card.

RAM-CARD TYPE 11 - 5 variables - 5 values

This card is needed only if option 6 is used to generate additional receptors for area coverage.

a) Distance between honeycomb receptors in user units.

b) Minimum east coordinate of boundary for area to be covered by receptors in user units.

c) Maximum east coordinate of boundary.

d) Minimum north coordinate of boundary.

e) Maximum north coordinate of boundary.

If b through e are entered as zero, the boundaries considered for these area sources will be the same as those of the area source region.

RAM-CARD TYPE 12 - 8 variables - 8 values

Cards of this type are needed only if option 11 is used. There should be a card for each hour to be modeled.

a) Year of meteorological data (2 digits).
b) Julian day of meteorological data (3 digits).
c) Hour of meteorological data (2 digits).
d) Stability class for this hour.
e) Wind speed (meters/second) for this hour.
f) Ambient air temperature (Kelvin) for this hour.
g) Wind direction (degrees) from which the wind is blowing, for this hour.
h) Mixing height (meters) for this hour.

To account for variability in emission rates with time in order to simulate emissions most accurately, it is possible to enter new emission rates for each of the sources for each simulated hour using option 13. In order to employ this option, emissions for each source must have been determined and written on two tape or disk files (one for point sources, one for area sources) with one record for each hour that is to be simulated. The emission information from RAMQ is still required and must be a "normal" emission rate in order that the exit velocity of the source can be scaled up or down in proportion to the hourly emission rate. Also, all permanent information about sources such as coordinates, physical stack height, and diameter are furnished by output from RAMQ.

RAMF and RAMFR

With few exceptions, which are easily noted in the example run streams, data inputs to RAMF and RAMFR are similar to those required by RAM and RAMR. In order to keep input lists the same for RAM and RAMF, even the list of option variables are the same, although values for options not available in RAMF are not even examined. (Values must be entered just to keep the variable lists the same length.) Options 4, 5, 6, 7, 8, 9, and 10 are not used in RAMF and RAMFR.

When using meteorological data from RAMMET, the start hour must be 1, and averaging times must be evenly divisible into 24. The averaging time must be 24 if the output data are to be used with the program CUMF. Days must be run in order but can be broken up into separate runs if desired.

When using meteorological data from cards, the start hour can be any integer from 1 to 24. The averaging time must be evenly divisible into 24 to run for multiple days. Days and hours on the meteorological data must be consecutive. The input parameter for the last day of the run must be input as the Julian day on the last hour's card to be processed. Care must be exercised in specifying this value when the start hour is not equal to 1.

CUMF

In addition to the disk file of 24-hour concentrations from RAMF or RAMFR, the data requirements are quite simple for CUMF. Two cards are required.

CUMF - CARD 1 - Up to 80 alphanumeric characters for the title to be used on the printed output and the plots.

CUMF - CARD 2 - 4 variables

a) The number of log cycles on the concentration scale.
b) The horizontal size of the plot (inches).
c) The vertical size of the plot (inches).
d) The minimum value of concentration on the concentration scale (micrograms/meter^3).

6. ALGORITHM CAPABILITIES

The capabilities of RAM are discussed by considering typical uses of various RAM programs and discussing an example problem for RAM.

TYPICAL USE OF RAM

The normal operation of RAM is to simulate the dispersion of pollutants released from point and area sources in an urban area over a period of one or two days. The meteorological data would be entered on cards, with a card for each simulated hour, using option 11. General emission information would be disk files generated by RAMQ, and hourly emission data would be entered from tape using option 13.

Most applications would consider both point and area sources using options 1 and 2. The locations of any existing air quality sampling stations would be used as specified receptor locations using option 3.

The use of options 4 and 5 to locate additional receptors downwind of significant point and area sources would assist in determining locations of maximum concentration. Since the resultant wind vector for the averaging period selected by the user is used to determine the direction of these receptors from the sources, averaging times as long as 12 to 24 hours that contain significant wind shifts may result in misleading calculated concentrations.

For example, if the wind is generally from 200° for a period of 10 to 12 hours (pollutant flow toward 20°), suddenly shifts to 280° (pollutant flow toward 100°), and remains in that general direction for the remainder of the 24-hour period, the resultant direction calculated by the model will be around 60°, although there were almost no hours of wind blowing pollutants in this direction. Therefore, concentrations will be very low in this direction from a given source but will be higher in the directions of 20° and 100° from the source. If attempting to locate high concentrations, it would be

better to run RAM for two periods, before and after the wind shift, using options 4 and 5. The locations of the higher concentrations could then be entered as receptor locations using option 3 for an additional run covering the entire period.

The user should note that when using options 4 and 5 to locate receptors downwind from significant sources, the locations of these receptors will shift for each averaging period dependent upon the resultant meteorological conditions for each period. Therefore, receptors with the same numbers will be at different locations for different averaging times.

If the user wants to obtain sufficient density of concentration estimates for a specific area so that pollution patterns are discerned, option 6 can be used to add additional receptors. The pattern used is such that adjacent receptors are equidistant. We refer to this as a honeycomb pattern. The distance between receptors is selected by the user. The boundaries of the area covered are also selected by the user. If the four boundaries are entered as zeros, the boundaries will be set to coincide with the boundaries of the area source map array.

Most modelers are aware, but it should be pointed out, that concentration gradients may be very steep, especially in the vicinity of plumes from point sources. Therefore, the addition of more receptors generally will reveal a more complex concentration pattern and usually some areas of higher concentrations. Therefore, in searching for maximum concentrations the individual user must decide on the point of diminishing returns as to receptor spacing commensurate with resources, analysis time, and the purpose of the project.

For the typical run, hourly output would be desired, so option 7 would be used. If option 7 is not employed, output is printed only for the specified averaging time. The use of option 8 to write partial concentrations onto a disk file will be used only if additional computer analysis is intended using the individual contributions of sources upon particular receptors. Computer programs to do this analysis must be written by the individual user to suit his purpose.

Option 9 is checked only if option 7 is used to get hourly summaries. The use of option 9 will print only a summary page for each hour. In this summary, in addition to giving the total concentration for each receptor, four other concentrations are given for each receptor: 1) the contribution to the concentration from all point sources, 2) the contribution to the concentration from all area sources, 3) the contribution to the concentration from all the significant point sources together, and 4) the contribution to the concentration from all the significant area sources together. The principal information that will be obtained by using option 7 but not option 9 is the contributions to the concentrations at each of the receptors from each of the significant sources. The maximum of 10 significant area sources results in an additional page of output per simulated hour. The maximum of 25 significant point sources results in three additional pages of output per simulated hour (one page for every 10 significant point sources or fraction thereof). Unless the concentration contributions are specifically needed for analysis of contributions from particular sources, option 9 should be used to reduce the quantity of output.

Option 10 would not be employed for this run unless the punched cards with concentrations for each receptor are desired for further analysis or they are to be used with graphics software to produce maps with concentration isopleths. As discussed previously, option 11 for meteorological card input and option 13 for entry of hourly emission data would be used. If the contributions to the concentrations at receptors from particular sources are of interest, and if these particular sources are not included high enough in the significant source lists from RAMQ to be included in the number of significant sources used in the run, option 12 may be used, and the sources of interest specified. In this case in addition to getting concentration contributions for the averaging time, it is probably desirable to use option 7 to obtain hourly output but not use option 9 so that the full hourly output is available.

DISCUSSION OF RAM EXAMPLE

An example of a test run for RAM is given in Volume II, Section 5 of this publication. This example is for a run simulating 2 hours. All options are

employed in this run with the exception of option 9. Option 9 would delete part of the hourly output.

For this run five disk files are assigned for the following five functions: 1) RAM program file, 2) output file from RAMQ containing primarily emission data, 3) an output file to receive the partial concentrations, 4) an input file containing the 1-hour emissions for each point source, and 5) an input file containing the 1-hour emissions for each area source.

The emission inventory for this example consists of 12 point sources and 15 area sources. The smallest rectangle that will include all area sources defines the area source region. The size of the smallest area source square is two user units on a side. The user unit is one mile since it is stated on the first page of the example output (see Volume II, Section 5) that there are 1.6093440 kilometers per user unit. The area source emission inventory has one source defined with a zero emission rate. This is area source 6. Time is saved in executing RAM by specifying areas of zero emission within the area source region that are larger than the smallest area source squares, with squares as large as possible. Note that point sources and receptor locations can be placed anywhere without regard as to whether they are inside or outside the area source region.

Note that, on the output under general input data, the height of the receptors above ground level must be the same for all receptors. The assumed pollutant half-life is used for all hours for the period simulated by the run.

The example run is executed by reading 14 data cards. All possible data cards are represented with the exception of card type 5 which is not needed to identify sources of meteorological data to compare with the disk file since option 11 is used reading meteorological data from cards. Cards 1, 2, and 3 are used to provide headings. Card 4 specifying choices for options and other required information is needed. Note that in this example the number of significant sources is specified as 5 for point sources and 10 for area sources.

A card of type 6 is required since both options 1 and 12 are used. It indicates that one point source is user specified and that it is source number 7.

The information on card type 7 on area sources is specified from a knowledge of the emission inventory and examination of the table from RAMQ output that shows the distribution of emissions with area source height. Three area source heights were selected with the 11-m height chosen to represent both the 10-m and 12-m sources.

The input information on area heights of emission may be confusing to the user. Area source heights may be expected to vary with wind speed, but little information pertaining to this is included in most emission inventories.

If the user wants the area source emission heights to remain constant throughout his run with no variation with wind speed, the first variable on card type 7, the fraction of the area source height that is physical height, should be entered as 1.

If the user wants to vary the area source height with wind speed, the area source heights input to RAMQ should represent the effective emission height from each area at a wind speed of 5 m s^{-1}. The fraction entered as the first variable on card type 7 should approximate as closely as possible the average physical height of each area source when the fraction is multiplied by the input area source height. To most effectively use this feature, the fact that both physical and effective heights are of interest should be known when conducting the emission inventory.

In the example the two heights used to determine which area source integration table to use appear in card type 8. It should be noted by the user that if only one area source height is used, one height should be read from card type 8, and its value should be higher than any area source height on the data used.

A card type 9 is required because both option 2 (area sources) and option 12 to specify specific numbered sources as significant are used. In this example option 12 is being used to specify only one point source which

was done with card type 6. The card of type 9 indicates that no area sources are being specified. The card of type 9 is still required.

Three cards of type 10 are used in this example to specify coordinates of two receptors input by the user. Note that the third card of this type is blank to signify the end of card type 10 input.

Since option 6 is used to generate additional receptors, one card type 11 is required. The first value on the card is the distance between receptors. The remaining variables are the boundary coordinates. If these are set to zeros on the input card, the boundaries of the area source region will be used. In this example an area smaller than the area source region is used.

The remaining two cards of input to the example are two hours of meteorological data on cards of type 12.

The output from the test run is reasonably easy to understand. The information under the headings: General Information from RAMQ, General Input Data, Point Source Information, Area Source Information, Area Source Map Array (IA), and Area Source Information are primarily from the RAMQ output transferred by disk.

The receptor locations input by the user are listed next. All location coordinates on RAM output are in the user's units that have been used for input.

The meteorological data and resultant conditions for the period are listed next. These resultant conditions are used in locating receptors downwind of significant sources.

The receptors located by the algorithm downwind of significant point and area sources are listed next. Note that RAM generates two receptors for each significant point source, one at the expected point of maximum for the resultant meteorological conditions, the other at twice this distance. The second receptor's placement is to allow for the possible interaction of pollutant plumes from several sources.

For the purpose of insuring good area coverage, the receptors are listed next under the heading "Generated Honeycomb Receptors." Note that in this example these cover only a portion of the area source region.

The concentration outputs follow next with three pages for each one-hour simulation: a page of concentrations from point sources, a page of concentrations from area sources, and one page with a summary table of concentrations.

Following the output for each hour are three pages of output for the averaging time of two hours: one page of concentrations from point sources, one page of concentrations from area sources, and one page with a summary table.

In this example the highest concentrations for both hours and for the two-hour period were at a receptor downwind of point source number 5.

TYPICAL RAMR USE

The only difference between RAM and RAMR is in the dispersion parameters used. RAM uses dispersion parameter values representative for urban areas; RAMR uses dispersion parameter values representative for open countryside. The full range of 13 options is available in both programs. A typical run using RAMR will not contain area sources. The presence of area sources will often, though not always, signify a sufficiently built-up area to require the use of urban dispersion parameters. An exception to this could be situations of pollutant releases from open areas such as particulate matter being raised by the wind from plowed fields or desert areas or other similar situations generally referred to as "fugitive" emissions.

TYPICAL RAMF USE

Many of the options available to RAM and RAMR are not available in RAMF and RAMFR. However, in order to keep input lists the same, dummy entries even for those options not used are made on input. Options not used are 4, 5, 6, 7, 8, 9, and 10. Options 1 and 2 are still used to indicate use of point and/or area sources. All receptors must be read as input to RAMF and RAMFR, so option 3 must be employed. Although it is generally expected that meteorological input will be from disk files prepared by RAMMET, option 11

may be used to enter data by punch card if more representative data are available. Because of the large number of card entries required for a lengthy period of record, input simulating the form of the data from RAMMET or a modification of the program to accept the meteorological data on tape or disk records may be considered as opposed to input on cards. In this case, the user must modify the program. Option 12 may be used giving the concentration contributions for the sources specified for the averaging period selected. Option 13 can also be used to input hourly emissions.

RAMF is primarily used to generate concentrations for an averaging time greater than an hour (generally 24 hours) for a period of record of one year so that this data can be input to the program CUMF to produce cumulative frequency distributions.

The RAM example, typical run streams, variable glossaries, and FORTRAN source codes are given in Volume II of this document.

REFERENCES

Briggs, Gary A., 1969: Plume Rise, USAEC Critical Review Series, TID-25075, National Technical Information Service, Springfield, Va. 81 pp.

Briggs, Gary A., 1971: Some recent analyses of plume rise observation, in Proceedings of the Second International Clean Air Congress, edited by H.M. Englund and W.T. Beery. Academic Press, New York. pp. 1029-1032.

Briggs, Gary A., 1972: Discussion on chimney plumes in neutral and stable surroundings. Atmos. Environ. 6: 507-510.

Briggs, Gary A., 1973: Diffusion Estimation for Small Emissions. Atmos. Turb. and Diff. Lab.,Contribution File No. (Draft) 79. Oak Ridge, Tenn. 59 pp.

Briggs, Gary A., 1975: Plume rise predictions, Chapter 3 (pp. 59-111) in Lectures on Air Pollution and Environmental Impact Analysis. Duane A. Haugen, editor, Amer. Meteorol. Soc. Boston, Mass. 296 pp.

Gifford, Franklin A., Jr., 1960: Atmospheric dispersion calculations using the generalized Gaussian plume model, Nucl. Saf. 2 (2): 56-59.

Gifford, Franklin A., and Hanna, Steven R., 1971: Urban air pollution modeling, in Proceedings of the Second International Clean Air Congress, edited by H.M. Englund and W.T. Beery. Academic Press, New York. pp 1146-1151.

Gifford, Franklin A., 1976: Turbulent diffusion-typing schemes: a review, Nucl. Saf., 17 (1): 68-86.

Holzworth, George C., 1972: Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution through the Contiguous United States, Office of Air Programs Publication No. AP-101. U.S. Environmental Protection Agency, Raleigh, N.C. 118 pp.

McElroy, James L., and Pooler, Francis, 1968: St. Louis Dispersion Study. Volume II-Analysis, National Air Pollution Control Administration. Publication No. AP-53. U.S. Dept. of Health Education and Welfare, Arlington, Va. 51 pp.

Novak, Joan Hrenko, and Turner, D. Bruce, 1976: An efficient Gaussian-plume multiple-source air quality algorithm, J. Air Poll. Control Assoc., 26 (6): 570-575.

Pasquill, Frank, 1961: The estimation of the dispersion of windborne material, Meteorol. Mag., 90 (1063): 33-49.

Pasquill, Frank, 1974: Atmospheric Diffusion, 2d ed., Halstead Press, New York. 429 pp.

Turner, D. Bruce, 1964: A diffusion model for an urban area. J. Appl. Meteorol., 3, 83-91.

Turner, D. Bruce, 1970: Workbook of Atmospheric Dispersion Estimates, Office of Air Programs Publication No. AP-26. US Environmental Protection Agency, Research Triangle Park, NC. 84 pp.

U.S. Environmental Protection Agency, 1974: User's Network for Applied Modeling of Air Pollution (UNAMAP). (Computer Programs on Tape for Point Source Models, HIWAY, Climatological Dispersion Model and APRAC-1A), NTIS PB 229-771, National Technical Information Service, Springfield, Va.

APPENDIX

An Efficient Gaussian-Plume Multiple-Source Air Quality Algorithm

Joan Hrenko Novak and D. Bruce Turner
U. S. Environmental Protection Agency

The information presented in this paper is directed to air pollution scientists with an interest in applying air quality simulation models. RAM is the three letter designation for this efficient Gaussian-plume multiple-source air quality algorithm. RAM is a method of estimating short-term dispersion using the Gaussian steady-state model. This algorithm can be used for estimating air quality concentrations of relatively stable pollutants for averaging times from an hour to a day in urban areas from point and area sources. The algorithm is applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a good approximation to the flow over the source area considered. Calculations are performed for each hour. Hourly meteorological data required are wind direction, wind speed, stability class, and mixing height. Emission information required of point sources consists of source coordinates, emission rate, physical height, stack gas volume flow and stack gas temperature. Emission information required of area sources consists of south-west corner coordinates, source area, total area emission rate and effective area source height. Computation time is kept to a minimum by the manner in which concentrations from area sources are estimated using a narrow plume hypothesis and using the area source squares as given rather than breaking down all sources to an area of uniform elements. Options are available to the user to allow use of three different types of receptor locations: 1) those whose coordinates are input by the user, 2) those whose coordinates are determined by the model and are downwind of significant point and area sources where maxima are likely to occur, and 3) those whose coordinates are determined by the model to give good area coverage of a specific portion of the region. Computation time is also decreased by keeping the number of receptors to a minimum.

Reprinted from **APCA JOURNAL**, *Vol. 26, No. 6, June 1976*

The purpose of formulating RAM is to provide a readily available computer program based on the assumptions of steady-state Gaussian dispersion. RAM can be used for any short-term (one-hour to one-day) determination of urban air quality resulting from pollutants released from point and/or area sources. Urban planners can use RAM to determine the effects of new source locations and of control strategies upon short term air quality. If the input meteorological parameter values can be forecast with sufficient accuracy, control agency officials can use RAM to predict ambient air quality levels, primarily over the 24-hour averaging time, to 1) locate mobile air sampling units, and 2) assist with emission reduction tactics. Especially for control tactics, diurnal and day-to-day emission variations must be considered in the source inventory input to the model. For most of these uses, the optional feature to assist in locating maximum points should be utilized. Computations are organized so that execution of the program is rapid, thus real-time computations are feasible.

Briggs' plume rise equations are used to estimate effective height of point sources. Concentrations from the point sources are determined using distance crosswind and distance upwind from the receptor. Considerable time is saved in calculating concentrations from area sources by using a narrow plume

Mrs. Novak is systems analyst, Model Development and Assessment Branch, and Mr. Turner is Chief, Environmental Applications Branch, Meteorology and Assessment Division, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. Both authors are on assignment from the National Oceanic and Atmospheric Administration, U. S. Department of Commerce. This paper was presented as Paper No. 75-043 at the 69th Annual Meeting of APCA at Boston in June 1975.

simplification which considers sources upwind from a receptor to be representative of those affecting the receptor. Area source sizes are used as given in the inventory rather than creating an internal inventory of uniform elements.

The algorithm is applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a reasonable approximation of the flow over the source area considered. A single mixing height and a single stability class for each hour are assumed representative of the area. The use of the RAM is restricted to relatively stable pollutants.

Options are available to allow the use of three different types of receptor locations: 1) those whose coordinates are input by the user, 2) those whose coordinates are determined by RAM and are downwind of significant point and area sources where maxima are likely to occur, and 3) those whose coordinates are determined by RAM to give good area coverage of a specific portion of the region. Options are also available concerning the detail of output produced.

The Algorithm

Inputs Required

The algorithm always requires emission and meteorological data, and depending on receptor options used, it may also require receptor data. Any convenient east-north rectangular coordinate system may be used since all conversion from user units to meters is performed internally by use of an input conversion factor.

A. Point source information consists of the following for each source:
   1. East coordinate of source location, user units
   2. North coordinate of source location, user units
   3. Stack height (above ground), meters
   4. Stack inside top diameter, meters
   5. Stack gas temperature, °K
   6. Stack gas velocity, m sec^{-1}
   7. Pollutant emission rate, g sec^{-1}

B. Area source information consists of the following for each source:
   1. East coordinate of the southwest corner of the area source, user units
   2. North coordinate of the southwest corner of the area source, user units
   3. Effective emission height, meters
   4. Side length of area source, user units
   5. Total pollutant emission rate for the area, g sec^{-1}

Area sources must be squares. They can be of various sizes, but their side length must be an integer multiple of a common side length. The term UNIT SQUARE refers to a source with this minimum common side length. The effective emission height of the area sources is assumed to be the effective height that occurs with a 5 m sec^{-1} wind. The effective height of the area sources can be varied with wind speed. Area emission rates are converted internally to g sec^{-1} m^{-2}.

C. Meteorological data, representative of the region being considered, consists of hourly values of the following:
   1. Wind direction, deg clockwise from North
   2. Wind speed, m sec^{-1}
   3. Stability class, dimensionless
   4. Mixing height, meters

   The stability class is that of Pasquill.

D. Receptor information, if required by user specification, consists of the following for each receptor:
   1. East coordinate of the receptor location, user units
   2. North coordinate of the receptor location, user units

Only one receptor height, z, above ground is allowed for a given execution of the model. This height can be zero or positive.

Basic Principles

The following assumptions are made: 1) Dispersion from points and area elements result in Gaussian distributions in both the horizontal and vertical directions through the dispersing plume, and therefore steady-state Gaussian plume equations can be used for point sources and the integration of these equations for area sources. 2) Concentration estimates may be made for each hourly period using the mean meteorological conditions appropriate for each hour. 3) The total concentration at a receptor is the sum of the concentrations estimated from all point and area sources, that is, concentrations are additive.

For point sources, the plume rise is calculated from the stack gas temperature, stack diameter, and stack gas velocity using the equations of Briggs.[1-3] The effective emission height is the physical stack height plus the plume rise.

In order to calculate contributions from point sources the upwind distance, x, and the crosswind distance, y, of each source from each receptor are calculated using Eq. A1 and A2

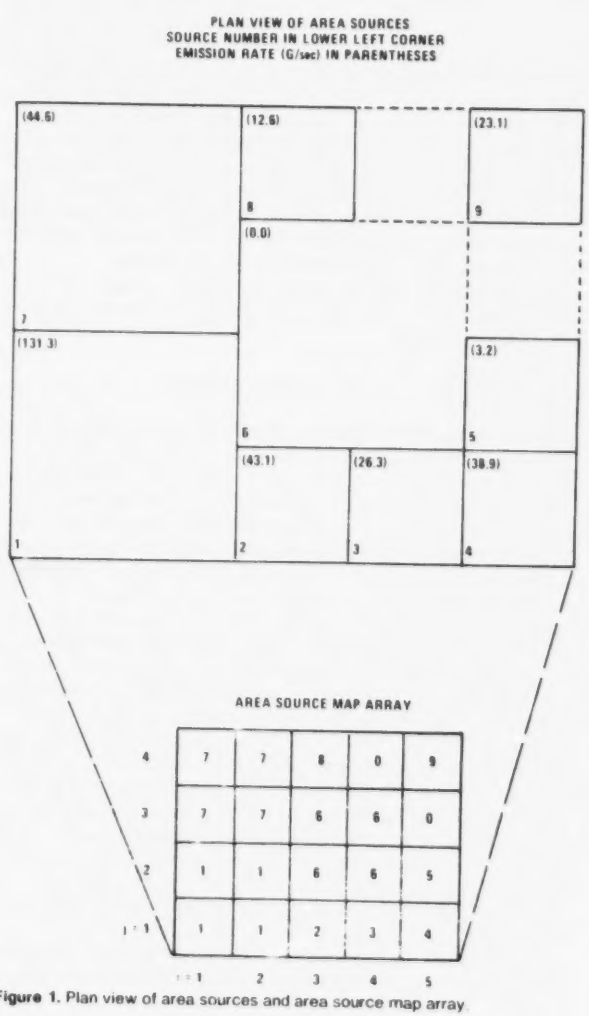

Figure 1. Plan view of area sources and area source map array

in the Appendix. The dispersion parameter values, σ_y and σ_z are determined as a function of the upwind distance, x, and stability class (See p 374 of Pasquill[4]). The three equations used to estimate concentrations under various conditions of stability and mixing height (Equations A3, A4, and A5) are discussed in the Appendix. These equations are for a receptor height, z, above ground and simplify considerably when the receptor height is assumed to be at ground level, $z = 0$. (Those simplifications are incorporated into RAM.)

The total concentration at a receptor arising from the two-dimensional area-source distribution is calculated using the narrow plume simplification of Gifford and Hanna.[5] This simplification is assumed because, on an urban scale, the plume from a point source release is normally quite narrow in comparison with the characteristic length scale for appreciable changes of the magnitude of the area-source emission rate itself. Under these circumstances the two-dimensional integral that expresses the total area-source contribution to concentration can be replaced approximately by a one-dimensional integral that only involves knowledge of the distribution of the area-source emissions along the line in the direction of the upwind azimuth from the receptor location, and the meteorologically-dependent function that specifies the crosswind-integrated concentration in the Gaussian plume from a point source. Further evidence for the validity of this approximation for treating area-source concentrations has been provided by some numerical tests of Thayer and Koch.[6]

In the use of this area source technique by Gifford and Hanna,[5] area source emissions were assumed at ground level allowing integration upwind to be accomplished analytically. However, in our application of this technique within RAM, the area sources are considered to have an effective height, thus requiring the integration to be accomplished numerically. The equations used to estimate concentrations from area sources (Eq. A10 through A13) are given in the Appendix. The total concentration from all area sources is determined by performing the integration in the upwind direction until the farthest boundary of the source region is reached.

Concentrations at a receptor for periods longer than 1 hr are determined by averaging the hourly concentrations over the period of interest.

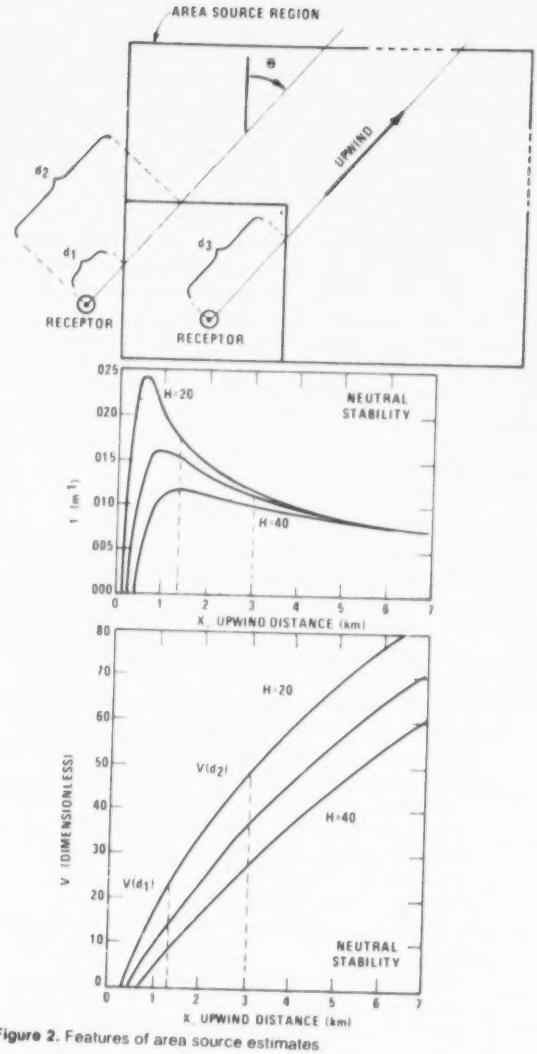

Figure 2. Features of area source estimates

How Computations Are Made

Initially, a preprocessor program is used to store the emission inventory in a convenient form and perform any necessary conversions. A most important function of the preprocessor is to arrange the area sources in such a way as to minimize computation time for area source concentrations. Each area source number (area sources are numbered sequentially as the sources are input) is stored in a two dimensional array which essentially forms a map of the relative locations of all the area sources. Each element in the array corresponds to an area the size of a unit square (previously defined). Therefore a unit source will have its source number stored into one element of the array, whereas an area source that is 4 units by 4 units will have its source number stored into 16 elements of the array (4 × 4). Obviously area sources must be mutually exclusive; they must not overlap. Array elements corresponding to areas of the source region not covered by area sources will have a zero stored in the array. As will be explained later, it is to the advantage of the user to define areas 2 × 2 units or larger with no emissions as specific source areas with zero emissions (source 6, Figure 1). An example of a simplified source region and the resulting array are shown in Figure 1.

Concentration estimates are made hour-by-hour for up to 24 hr. This algorithm is not designed to determine average concentrations over periods longer than 24 hr. First, concentrations resulting from area sources are calculated. In an effort to reduce the total amount of computer time, tables (arrays) which contain relative concentrations, V, normalized for emission rate and wind speed, are calculated only once for each simulated hour using the appropriate stability and mixing height, and thereby eliminating all repetitive calculations. The function V is calculated from:

$$V(d) = \int_0^d f \, dx \qquad (1)$$

and is the non-dimensional concentration resulting from an area source of given effective height extending upwind from a receptor to the distance, d. The function f, whose form depends on stability, and mixing height, is defined in the Appendix (Eq. A11, A12, and A13). The stored tables contain values of this integral obtained by numerical integration for a number of values of d. Both f and V for 3 area source heights are shown in Figure 2. Because $V(d)$ changes rapidly for small values of d, the numerical integration using the trapezoidal rule is done using varying size intervals, as small as 1 meter

for x less than 100 meters, and as large as 1 km for x greater than 15 km. The values of V are also stored for varying intervals of d (ranging from 10 m to 1 km), so that linear interpolation between stored values will result in an accurate estimate of V. For each effective area source height, up to a maximum of three, a V table is generated and stored at the beginning of each simulated hour.

The concentrations from the area sources are computed receptor by receptor. If the receptor is outside the source region (the rectangular region containing all the area sources), it is first determined if the upwind ray (the line pointed in the wind direction) intersects the source region. If it does not intersect the source region, no contribution from area sources at this receptor is calculated. If the upwind ray does intersect the source region, the distance, d_1, (See Figure 2) along the ray to the source region is determined using Eq. A6 and A8 in the Appendix. The coordinates of this intersection point and consideration of wind direction provide direct access, through the area source map array, to the source number of the particular area source at this intersection point. Since all other source information is stored in arrays indexed on source number, the area source location (coordinates of SW corner), size, effective height, and emission rate are readily available.

Knowledge of the location and size of the area source permits the calculation of the intersection point of the upwind ray from the receptor with the area source boundary on the other side of the source (See Equations A6 through A9 in Appendix) and subsequently the calculation of distance (d_2) from the receptor to this point (Figure 2). These two distances, d_1 and d_2, are then used to obtain linearly interpolated values of V from the tables, $V(d_2)$ and $V(d_1)$. The concentration from this source (assume this is source number i) is then given by:

$$\chi_{Ai} = (q_{Ai}/u)[V(d_2) - V(d_1)] \qquad (2)$$

where χ_{Ai} is the concentration at the receptor from the ith area source, q_{Ai} is the area source emission rate from the ith area source, and u is the mean wind speed. $V(d_1)$ is subtracted since it represents the area source contribution not present. If, however, the emission rate is zero or the source number stored in the area source map array is zero, the source does not contribute to the concentration, but the intersection with the boundary and the distance to this intersection is determined as before.

After estimating the contribution of this area source to the receptor, the coordinates at the boundary furthest from the receptor are used to determine the next adjacent source entered by the upwind ray. The procedures are then repeated for this source and all other sources until the boundary of the area source region is reached by working upwind along the upwind ray.

In the case where the receptor is initially within the area source region, the coordinates of the receptor are used to determine within which area source the receptor lies. If the source number is zero, indicating no source area, the intersection point of the upwind ray and the upwind boundary of a unit square is determined and computation proceeds as above. If the receptor is within a numbered source area, the intersection point of the upwind ray and the upwind area source boundary, see Figure 2, as well as the distance, d_3, to this point are determined. Then by interpolation in the V table corresponding to the appropriate area source height, the contribution to the concentration is computed as follows:

$$\chi_{Ai} = (q_{Ai}/u)V(d_3) \qquad (3)$$

The next area source upwind is determined and computations proceed for the other upwind sources as above. The advantage of specifying large areas of no emission, rather than leave them numbered as zero in the area source map array, is that the intersection of the upwind ray and the far boundary can be determined directly rather than stepping across a number of unit squares.

After the influence of area sources upon all receptors is calculated for a simulated hour the contribution from point sources is determined. Concentrations from point sources are also calculated receptor by receptor; and for each receptor, calculations are made source by source. The upwind distance, x, of the point source from the receptor is determined for this hour from the coordinates of the point source, the coordinates of the receptor, and the wind direction (See Eq. A1 in the Appendix). If this distance is negative, the source does not contribute to the receptor and the next source is examined. However, if the upwind distance is positive, the crosswind distance, y, and the ratio y/σ_y are determined next. If y/σ_y is greater than 10, the factor g_1 (See Appendix) is always so small that the contribution from this point source to the receptor is negligible. But with y/σ_y less than 10 an additional test must be made to see if the concentration is significant. If the factor g_1 multiplied by the point source emission rate is less than some specified threshold concentration, no further calculations are made for this source.

In most cases the concentration is above the threshold, and plume rise must be calculated for the source being considered provided that it was not calculated previously for estimates at another receptor for this simulated hour. A table of final plume heights and distance to the final rise is filled in as plume rise calculations are required, thus final plume rise is calculated only once for each source for each hour's simulation. If the upwind distance of the source from the receptor, x, is less than the distance to final plume rise, the gradual rise of the plume from stack top to final rise is considered, and the plume height at this nearer distance is used for estimates for this receptor. After the appropriate plume rise is obtained, the concentration at the receptor from this point source is calculated using the equation appropriate for stability class and mixing height as discussed in the Appendix. Concentrations from other point sources are similarly determined. Similar procedures are repeated then for each of the other receptors.

The total concentration at a receptor is the sum of the concentrations from area sources and from point sources. If any background concentration exists that is caused by sources outside the source region, it must be added to the concentration estimates from RAM.

Options

Three options are available regarding use of receptor locations in RAM. The first option allows coordinates of specific receptors to be entered as input.

Use of the second receptor option allows the user to specify how many significant point and how many significant area sources he wants to consider. The model then calculates the location of the maximum concentration from each significant point source using a plume rise calculation, the resultant wind direction, and the most frequently occurring (modal) stability class during the period modeled (24 hr or less). (It is not desirable to use this option if there are significant shifts of the wind during the period modeled, because the resultant direction will not represent the mean transport.) A receptor is located at the estimated point of maximum from each significant source, and another in the same direction but twice as far away. A receptor at this second distance may also have high concentrations for cases of overlapping plumes from several sources. Using this second receptor option there are two receptors established for each significant point source.

The second receptor option also determines the location of a single receptor downwind of each significant area source. Since the effective height of area sources are generally lower than point sources, the maximum concentration from the area source is calculated quite near the boundary of the source.

The location of the maximum concentrations from specific point and area sources will, of course, not necessarily be a location where the contribution from all sources will result in a maximum. Since the location of the maxima are highly dependent upon the dispersion parameter values, σ_y and σ_z, any modification of the algorithm that changes the way in which these dispersion parameters are calculated will also require extensive modifications to the subroutines, which determine the maximum distances from point and area sources, if the second receptor option is to be used.

The third receptor option allows for good area coverage of a specified portion of the region. The boundaries of the region to be covered and the spacing between receptors, w, are specified by the user. In order to cover the maximum area with the fewest number of stations, a hexagonal or 'honeycomb' grid is used. Receptor locations are at equal distances from nearby receptors so that if lines are drawn to all nearby receptors, six equilateral triangles will result. Also in order to keep the total number of receptors to a minimum, any potential receptor locations generated by the third option are deleted if they are within one-half w of any other existing receptor.

Several other options available are mainly used to delete special output when not required. These options are not as significant as the receptor options and will not be discussed here.

Summary

RAM is a steady state Gaussian algorithm applicable to urban areas for pollutants emitted from point and area sources. Calculations are made for one-hour time periods. Average concentrations may be obtained for time periods up to 24 hr.

Estimation of concentrations from point sources is straightforward. Briggs' plume rise equations are used. Upwind and crosswind distances of each source from each receptor are determined and concentration is estimated from various Gaussian equations.

Innovative techniques are used in keeping the number of receptors to a minimum and in the treatment of the area emission inventory. Except for the area source map array used for coordinating area source number with location, area source information is stored and used directly for a number of possible source sizes. A narrow plume simplification with consideration of source height of each area is used. The emission rates of the area sources in the source region along the upwind azimuth are considered representative of the area emission rates affecting the receptor from various distances upwind (narrow plume hypothesis). Determination, at the beginning of each simulated hour, of the effect of area sources extending to different distances upwind are stored in tabular form with a different table for each effective area source height (up to 3 heights allowed). Linear interpolation of these tabular values for each source, and receptor by receptor, to obtain concentrations from area sources saves considerable computer time.

The various receptor options in the model allow for versatility in the use of RAM. Coordinates corresponding to fixed locations, such as air quality sampling locations may be used. In attempting to estimate maximum concentrations for particular short term periods, the option to select locations downwind of particularly significant sources can be used. To insure good area coverage, an option is available to select additional receptors equally spaced from each other. These equally spaced receptors cover a particular defined region and are added only if other receptors have not been located in the vicinity of each proposed receptor location.

A user's guide for RAM is under preparation. One version of this algorithm has been applied to a 3-month urban data base related to sulfur dioxide. In order to assess the validity of the model, comparisons of these estimates with measurements are being accomplished by a group under Dr. Patrick Hamill at Clark College in Atlanta. It is anticipated that the algorithm will soon be made available to users as part of EPA's User's Network for Applied Modeling of Air Pollution (UNAMAP).

Acknowledgment

The authors appreciate the assistance of Lea Prince.

References

1. Gary A. Briggs, *Plume Rise*, USAEC Critical Review Series, TID-25075, National Technical Information Service, Springfield, VA 22161, 1969.
2. Gary A. Briggs, "Some Recent Analyses of Plume Rise Observation," in *Proceedings of the Second International Clean Air Congress*, edited by H. M. Englund and W. T. Beery, Academic Press, New York, 1971, pp 1029–1032.
3. Gary A. Briggs, "Discussion on chimney plumes in neutral and stable surroundings," *Atmos. Environ.* **6**: 507 (1972).
4. F. Pasquill, *Atmospheric Diffusion*, 2nd ed., Halsted Press, John Wiley & Sons, Inc., New York, 1974, p. 374.
5. F. A. Gifford, Jr. and Steven R. Hanna, "Urban Air Pollution Modelling," in *Proceedings of the Second International Clean Air Congress*, edited by H. M. Englund and W. T. Beery, Academic Press, New York, 1971, pp 1146–1151.
6. Scott D. Thayer and Robert C. Koch, "Validity of the Multiple-Source, Gaussian Plume Urban Diffusion Model Using Hourly Estimates of Input," in *Preprint Volume of the Conference on Urban Environment and Second Conference on Biometeorology*, Oct. 31–Nov. 2, 1972, Philadelphia, PA, published by Amer. Meteorol. Soc., Boston, MA.

Appendix

Dispersion and Analytic Geometry Equations Used in RAM

Expressions

These expressions are used in the discussions that follow:

$$g_1 = \exp(-0.5y^2/\sigma_y^2)$$

$$g_2 = \exp[-0.5(z-H)^2/\sigma_z^2] + \exp[-0.5(z+H)^2/\sigma_z^2]$$

$$g_3 = \sum_{N=-\infty}^{\infty} [\exp[-0.5(z-H+2NL)^2/\sigma_z^2] + \exp[-0.5(z+H+2NL)^2/\sigma_z^2]]$$

(This infinite series converges rapidly and evaluation with N varying from -4 to $+4$ is usually sufficient.)

where

- H = effective height of emission, meters
- L = mixing height, the top of the unstable layer, meters
- y = crosswind distance, meters
- z = receptor height above ground, meters
- σ_y = standard deviation of plume concentration distribution in the horizontal, meters
- σ_z = standard deviation of plume concentration distribution in the vertical, meters

Reproduced from best available copy.

Point Source Computations

The upwind distance, x, and the crosswind distance, y, of a point source from a receptor are given by:

$$x = (S_p - S_r)\cos\theta + (R_p - R_r)\sin\theta \quad \text{(A1)}$$

$$y = (S_p - S_r)\sin\theta - (R_p - R_r)\cos\theta \quad \text{(A2)}$$

where R_p, S_p are the coordinates of the point source; R_r, S_r are the coordinates of the receptor, and θ is the wind direction (the direction from which the wind blows). The units of x and y will be the same as those of the coordinate system R, S. Frequently a conversion is required in order to express x, and y in meters or kilometers.

The contribution to the concentration, χ_p, from a single point source to a receptor is given by one of the three following equations where χ_p is in g m^{-3}, Q is point source emission rate in g sec^{-1}, u is wind speed in m sec^{-1}, and σ_y and σ_z are evaluated for the upwind distance x, and the stability class.

For stable conditions or unlimited mixing:

$$\chi_p = Qg_1g_2/(2\pi\sigma_y\sigma_z u) \quad \text{(A3)}$$

In unstable or neutral conditions and if σ_z is greater than 1.6 times the mixing height, L, the distribution below the mixing height is uniform with height provided that both the effective height, H, and the receptor height, z, are below the mixing height:

$$\chi_p = Qg_1/[\sigma_y Lu(2\pi)^{1/2}] \quad \text{(A4)}$$

(If H or z is above the mixing height, $\chi_p = 0$.)

In all other unstable or neutral conditions, that is, if σ_z is less than 1.6 times the mixing height:

$$\chi_p = Qg_1g_3/(2\pi\sigma_y\sigma_z u) \quad \text{(A5)}$$

Area Source Computations

Some analytic geometry relationships are used in estimating concentrations from area sources.

The distance, d_1, along an upwind ray in the direction θ from a receptor R_r, S_r to a north-south boundary given by $R = R_b$ is:

$$d_1 = (R_b - R_r)/\sin\theta \quad \text{(A6)}$$

The east coordinate of the locus of the boundary and the upwind ray is, of course, R_b. The north coordinate of this intersection is:

$$S_L = S_r + d_1\cos\theta \quad \text{(A7)}$$

The distance, d_2, along an upwind ray in the direction θ from a receptor R_r, S_r to an east-west boundary given by $S = S_b$ is:

$$d_2 = (S_b - S_r)/\cos\theta \quad \text{(A8)}$$

The north coordinate of the locus of the boundary and the upwind ray is, S_b. The east coordinate of this intersection is:

$$R_L = R_r + d_2\sin\theta \quad \text{(A9)}$$

(Depending upon the units of the coordinate system R, S, the results of these equations may have to be multiplied by a factor to convert to meters).

The contribution of the concentration, χ_A, from a uniform area source directly upwind of a receptor is:

$$\chi_A = (q_A/u)\int_{x_1}^{x_2} f\,dx \quad \text{(A10)}$$

where χ_A is in g m^{-3}, q_A is area source emission rate in g sec^{-1} m^{-2}, u is wind speed in m sec^{-1}, x_1 is the distance in meters from the receptor to the locus of the upwind ray (extending from the receptor) and the closest boundary of the area source, x_2 is the distance in meters from the receptor to the locus of the upwind ray (extending from the receptor) and the distant boundary of the area source, and f is given by one of the three equations below. The integral in the preceeding equation is evaluated numerically.

For stable conditions or unlimited mixing:

$$f = g_2/[\sigma_z(2\pi)^{1/2}] \quad \text{(A11)}$$

In unstable or neutral conditions and if σ_z is greater than 1.6 times the mixing height, L, the distribution below the mixing height is uniform with height provided that both the effective height, H, and the receptor height, z, are below the mixing height:

$$f = 1/L \quad \text{(A12)}$$

(If H or z is above the mixing height, $f = 0$.)

In all other unstable or neutral conditions, that is, if σ_z is less than 1.6 times the mixing height:

$$F = g_3/[\sigma_z(2\pi)^{1/2}] \quad \text{(A13)}$$

Date_____

Chief, Environmental Applications Branch

Meteorology and Assessment Division (MD-80)

U.S. Environmental Protection Agency

RESRCH TRI PK, NC 27711

I would like to receive future revisions to the *User's Guide For RAM, Vol. I.*

Name_____

Organization _____

_____

Address_____

City_____ State_____Zip_____

Phone (Optional) (____) _____ - _____

* U.S. GOVERNMENT PRINTING OFFICE: 1979--740-311/41st Region No. 4